Barriers and Bridges to the Renewal of Ecosystems and Institutions

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Editors

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I am the love that initiates and the truth that passes away.
All that compels acceptance and all that brings renewal;
all that breaks apart and all that binds together;
power, experiment, progress, matter:
all this am I.

Hymn of the Universe
Teilhard de Chardin

Contents

Preface

This book explores ways for active adaptation and learning in dealing with uncertainty in the management of complex regional ecosystems. We present the book as twelve chapters grouped in four sections. The first section consists of the introductory chapter, where a common pattern of resource development is presented and diagnosed, and an emerging theory is suggested to explain that pattern. The heart of the book is in the next section, where six case studies of regional ecosystem management are presented in chapters 2–7. The goal was to test and expand the diagnosis of the first chapter and to refine and extend theory. This set of case studies is perhaps unique, because each case was explored by one or two individuals with considerable scholarship, direct experience in the policies and politics of the region, and the ability to communicate to a wide audience. The case studies are followed by a third section of four chapters written by social scientists who comment on the case studies and the emerging theories from a perspective of their own experience and expertise. These perspectives include political science, Third World development, learning theory and practice, and institutional psychology. We conclude with the fourth section, a chapter that presents a synthesis of social science theory and ecological theory to explain the observed patterns of frustrating resistance of institutions to change and the sudden lurches of learning that can occur.

How the Book Was Born

The book is the result of a three-year research project established to deal with two key questions: (1) Do institutions learn, and if so how? and (2) How do ecosystems respond to management actions? An international team of scholar/practitioners was organized to begin a series of comparisons of regional development experience. This was given focus by posing the series of postulates described in the introduction that seemed to represent common patterns observed over time in managed ecosystems. The postulates describe a progression of ecosystems that become less resilient, management agencies that become more efficient but more myopic, industries that become more dependent and static, and a public that loses trust. This can lead to a crisis triggered by unexpected external events, followed by a reformation of policy. The initial goal was to see if these patterns were observed in the history of regional ecosystems as interpreted by people firmly embedded in understanding the natural and human dimensions of the system. These case studies form the empirical foundation for the book.

Following a set of preliminary organizational meetings, the first workshop was held in October 1991 and was attended by most of the case study authors (Holling, Baskerville, Light, Gunderson, Costanza, Lee, Regier, and Francis) to discuss the applicability of patterns in their respective regions. A second workshop was held in April of 1992, when the case study authors met again to share findings and first-draft presentations with a broader group including the essayists: Steve Sanderson, Bill Clark, Frances Westley, and Don Michael. In addition, E. Walt Coward, Tim Clark, Greg Daneke, Gilberto Gallopin, Clyde Kiker, Steve Minta, and Harry Vredenberg participated in the April workshop and contributed to ideas that are presented in the text.

What We Learned in the Process

This book is the fourth in a set that deals with adaptive resource and environmental management. The first in that series, *Adaptive Environmental Assessment and Management* (Holling 1978), defined issues and approaches for dealing with the known, uncertain, and unknown dynamic facing and caused by management. The second, *Adaptive Management of Renewable Resources* (Walters 1986), is becoming something of a classic in its description of brilliantly innovative quantitative methods for analyzing, designing, and monitoring actively adaptive resource management systems. The third, *Compass and Gyroscope: Integrating Science and Politics for the Environment* (Lee 1993), uses the insights of a political scientist and the pen of a poet to describe the political context for adaptive approaches. It emphasizes the critical requirements for a democratic process in which the citizen must deal with the complexity and ambiguity of resource and environment issues.

This fourth book is one both of social and ecological theory and of empirical practice. Enough examples of regional experience have accumulated in the last fifteen years that we hoped the case studies would provide examples of pathologies and positive learning experiences, that is, of barriers and bridges to learning, especially in cases where adaptive techniques had been applied. The book deals equally with the way ecosystems are structured and behave and how institutions and the people associated with them are organized and behave.

One of the surprises of this analysis is that both ecological and social systems are inherently more dynamic and unpredictable than was first imagined. All the case studies exposed a profound but potentially transient pathology of resource development. This pathology generally results in a crisis, when the existing policies are recognized clearly as no longer being adequate, followed by a reformation and adoption of new policies. The effort to develop a coherent theory of structural and incremental change in ecosystems and institutions has led to a heuristic framework that seems to capture much of the dynamics of ecosystems and institutions as they continually co-evolve. Moreover, the heuristic suggests ways to identify critical needs during different phases of change, the ways to respond to those needs, and the ways not to respond. We have attempted to move beyond an analysis of stochastic events and patterns of behavior, and have begun to probe a logic of change itself. This and future studies will provide foundations for adaptive management of complexity—to learn to manage *by change* rather than simply to react to it.

We could summarize our specific findings in abstract scholarly terms, but these do not do justice to the reality. The reality is that individuals and small groups of individuals exert extraordinary influence by performing certain distinct roles within and outside institutions. It is this influence that provides a partial antidote to the people who perpetuate equilibrium-centered, command-and-control strategies that often permeate bureaucracies as they ally themselves, often unconsciously, with the power lobbyists to subvert the democratic process. We identified six critical roles, and each is associated with specific names of outstanding individuals who exemplify those functions:

- The creatively destructive role of public interest groups.
- The alerting role of loyal heretics within agencies.
- The importance of "gray eminences"—respected, wise individuals who synthesize, integrate, and communicate information.
- The redefining role of informal collegia of natural scientists, engineers, and social scientists operating outside formal institutions.
- The strategic design and research role of adaptive council in systemwide governance.
- The democratic political role of citizen science.

Acknowledgments

No project like this can succeed without fiscal and administrative support. A few individuals filled these crucial roles. Above all, E. Walter Coward, Jr., provided the encouragement and the bulk of the financing through the Rural Resources and Poverty Program of the Ford Foundation. By so doing he provided the independence and flexibility rarely possible when funding is constrained by government agencies. Timer Powers and Til Creel, executive directors of the South Florida Water Management District, were both brave and wise enough to look outside their boundaries to encourage the search for ways to learn to manage complex regional ecosystems. Consequently, the South Florida Water Management District provided partial funding for the work within Florida. Finally, the financial support of Eugene Stakhiv of the U.S. Army Corps of Engineers allowed us to pay the essayists. Without the collective foresight and trust of these people the project would have been impossible.

Financial support was also provided by the University of Florida Foundation, through the Arthur R. Marshall, Jr. Endowed Chair in Ecological Sciences. Administrative support was supplied by Candy Lane and Toni Carter at the University of Florida and Cherilyn Gerkovich at the South Florida Water Management District. Ilse Holling created the "Field of Dreams" atmosphere for the workshops and is rumored to have arranged for the lightning bolt at Ichetucknee River that reminded us continually to expect the unexpected. Other acknowledgments are found at the end of each chapter. We are grateful for the help of Ronald Harris for copyediting and all the people at Columbia University Press, especially Ed Lugenbeel, who saw the value in publishing this project. Of course, no acknowledgment would be too much for Ralf Yorque, University of McMurdo Sound, our mentor and source of inspiration.

Lance Gunderson, Buzz Holling, and Steve Light

Barriers and Bridges to the Renewal of Ecosystems and Institutions

Part 1
Introduction

1

What Barriers? What Bridges?

C. S. Holling

For the past few decades regional resource and environmental policy and management have been in and out of decision gridlocks in many regions of North America, Europe, and Australia. When issues are polarized, it is a time of deep frustration. Conflicts are extreme, mutual suspicions dominate, and cooperation seems the road to personal defeat. Identifying an enemy and utterly destroying him or her seem more important than finding win/win solutions. The result can be ecosystem deterioration, economic stagnation, and growing public mistrust. Alternatively, the result can be an abrupt reevaluation of the fundamental source of the problems, a redirection of policy toward restoration, and implementation of a process of planning and management that provides continually updated understanding as well as economic or social product.

The purpose of this book is to review a set of regional examples of resource and environmental policy and management where periods of crisis and polarization seem to be replaced either by a paralysis in decision making, exhausted apathy, or active adaptive learning. We want to discover if there are common features to all examples that identify critical barriers to and bridges for maintaining, renewing, or restoring the ecological attributes and institutional flexibility that underlie and provide services to the people and activities in a region.

The cases cover forest management in New Brunswick; water management for agriculture, cities, and ecosystems of the greater Everglades system in Florida; estuarine management in the Chesapeake Bay; salmon and power in the Columbia River; water quality, fisheries, and development in the Great Lakes; and the same issues in the Baltic Sea.

Such problems are not purely ecological, economic, or social. They are a combination of all three and require understanding of the interrelations between nature and people in different settings, performing different roles. Nevertheless, it will seem that much of this analysis is provided by recent advances in understanding the way ecological systems are structured and function—theories that have evolved out of examining and modeling natural processes. We sensed that some of these attributes of ecological systems are really attributes of any complex, evolving system, so that they might also structure the functioning of the economies and institutions that interact, often in hidden ways, with ecosystems. Thus the more fundamental aspect of the book was to evaluate those apparent similarities.

This is not, however, a formal effort to disprove alternative hypotheses in the traditions that led to the ecological theories. It is too soon for that. Rather, it is an effort to define a new set of interesting questions, the hypotheses that might well be testable, and the experiments in policy and management that might be part of those tests.

The need is generally evident. But we believe a new dimension is beginning to be added to local and regional problems that transforms them into a new class. At the same time that local and regional adaptive capabilities are eroding in some regions, intensifying global connections are becoming more evident. The resulting surprises seem to be almost archetypal unknowns. AIDS, the ozone hole, species extinction, and possible climatic change are occurring because of human transformations of local landscapes or of the atmosphere. These changes spread and become global.

The processes that make them problems are all fundamentally ecological, environmental and evolutionary. Although its origins are controversial, some evidence suggests that AIDS, for example, moved from simian to human populations. Initially, it was not virulent, but it evolved into a more deadly form as rates of transmission increased because of social disruptions arising from transformation of land, urbanization, and population increases (Morse 1993). That also has been the story of malaria in Africa (Desowitz 1991). But, unlike malaria, HIV requires no intermediate vector, so that the intensified movement of people around the planet turned a disease that was local and potentially self- extinguishing, into the present intensifying global pandemic. The consequences of these transformations reveal humanity as a planetary force, and perhaps one that is out of control.

So how does a regional politician react in these circumstances? How does the head of a regional resource management agency react? In the United States fewer administrators are now confidently proposing immediate solutions and practical actions to ecological and environmental problems than in the 1970s. The world is now too confusing. At the extreme, some are asking for more and more precision of data about more and more variables in order to be invulnerable in a courtroom! This is an attitude that does not see science as useful in diagnosing emerging problems or in providing a foundation for the integrated understanding needed for policy design. Rather, it views science's role as the provider of data needed for litigation.

But the issue should not be seen as a lack of certainty and precision of data or of predictions. Rather, there is a fundamental loss of certitude—loss in the belief that any of the ground rules work anymore. Any action seems to be full of costs and without benefit. The only comfort is a retreat to unsupported ideology and beliefs.

There are two responses. One is to seek a spurious certitude by increasing control on information and action. The U.S.S.R. learned the price of that strategy! The other is to seek understanding.

This is the motive for this book. For all the bad-news stories, there are signs of an alternative stream of experience. Certainly there are many local examples within developed countries where air has been made clearer and water cleaner. Areas of unsustainable agriculture have been successfully reforested. But how generic are the local successes? Is a new class of regional and global issues being dealt with in another complex phase of learning?

This chapter was written initially to provide guidance for the case studies that were chosen to answer this question. It was intended to provide a set of postulates to be tested and a consistent framework of analysis and synthesis, so that the project and resulting book could be much more than a simple compendium of independent studies.

The first section of this chapter diagnoses a fundamental pathology that has been identified in examples of ecosystem management, a diagnosis that leads to a set of postulates and a set of case studies to explore those postulates. The second section attempts to understand that pathology and its potential cure by first explaining why science and scientists seem so often to succeed in identifying potential problems but to fail in agreeing what to do about them. The third section lays the foundation for understanding the patterns of change in complex systems of nature and people as a possible framework to design creative responses to the inevitable surprises that nature and our actions generate. The final section uses that theoretical treatment to argue that sustained development is only possible if it is seen as a process of evolutionary change that rests on the capacity of nature and people for renewal.

A Diagnosis

My first sense that some of the present problems and responses fall into a new class came when I reviewed some twenty-three examples of managed ecosystems (Holling 1986). Those examples fell into four classes—forest insect, forest fire, savanna grazing, and aquatic harvesting. Two puzzling features were exposed by the initial comparison. One concerned the way ecosystems are organized. The other involved the way ecosystems are managed. Both have turned out to be the consequence of the natural workings of any complex, evolving system.

The first puzzle suggested that the great diversity of life in ecosystems is traceable to the function of a small set of variables, each operating at a qualitatively different speed from the others. The steps for solving that puzzle led to a grand journey collecting data and testing hypotheses that dealt with the morphology, geometry, and dynamics of ecosystems. It is presented in detail elsewhere (Holling 1992), and I shall review the results briefly toward the end of this chapter because they indirectly bear on the nature of policies that are adaptive and sustainable.

The second puzzle is the central focus for this book. It suggested that any attempt to manage ecological variables (e.g., fish, trees, water, cattle) inexorably led to less resilient ecosystems, more rigid management institutions, and more dependent societies. It was this puzzle of success leading to failure that, more than anything else, launched this book's effort to compare regional experiences. As a consequence, I shall dwell a bit more on the postulates that emerged as this puzzle was explored further. Those postulates guided the case study analyses.

All twenty-three examples were associated with management of a resource where the very success of management seemed to set the condition for collapse. In each case the goal was to control a target variable in order to achieve social objectives, typically maintaining or expanding employment and economic activity. In the case of management of eastern North American spruce/fir forests, for example—the target was an anticipated outbreak of a defoliating insect, the spruce budworm (Baskerville, chapter 2; Clark et al. 1979); for the forests of the Sierra Nevada Mountains the target was forest fires (Holling 1980); for the savannas of South Africa the target was the grazing of cattle (Walker et al. 1969); for the salmon of the Pacific Northwest coast the target was salmon populations (Walters 1986).

In each case the goal was to control the variability of the target—insects and fire at low levels, cattle grazing at intermediate stocking densities, and salmon at high populations. The level desired was different in each situation, but the common feature was to reduce variability of a target whose normal fluctuations imposed problems and periodic crises for pulp mill employment, recreation, farming incomes, or fishermen's catches.

The typical response to threats of fire or pestilence, flood or drought is to narrow the purpose, focus on it exclusively, and solve the problem. Modern engineering, technological, economic, and administrative experience can deal well with such narrowly defined problems. And these threats were countered: Insects were controlled with insecticide; fire frequency and extent were reduced with fire detection and suppression techniques; cattle grazing was managed with modern rangeland practice; and salmon populations were augmented with hatchery production.

At the same time, however, elements of the system were slowly changing as a consequence of the initial success of the policy. And because the problem was defined narrowly, such changes were not perceived. First, reducing the variability of the ecological target produced a slow change in the spatial heterogeneity of the ecosystem. Forest architecture became more contiguous over landscape scales, so that if defoliating insects or fire were released, the outbreaks could cover larger areas and have a greater impact than before management. Rangeland gradually lost drought-resistant grasses because of a shift in competition with more productive but more drought-sensitive grasses. If drought occurred, the consequences were more extensive, extreme, and persistent, so that grasslands turned irreversibly into shrub-dominated semideserts. Wild populations of salmon in the many streams along the coast gradually became extinct because fishing pressure increased in response to the increased populations resulting from enhancement. That left the fishing industry precariously dependent on a few hatcheries whose productivity declines with time.

In short, the success in controlling an ecological variable that normally fluctuated led to more spatially homogenized ecosystems over landscape scales. It led to systems more likely to flip into a persistent degraded state, triggered by disturbances that previously could be absorbed. This is the definition for loss of resilience (Holling 1973).

Those changes in the ecosystems could have been managed were it not for concomitant changes in two other elements of the interrelationships—in the management institution(s) and in the people who reaped the benefits or endured the costs. Because of the initial success, in each case the management agencies shifted from their original social and ecological objectives to the laudable objective of improving operational efficiency of the agency itself—spraying insects, fighting fires, producing beef and releasing hatchery fish with as much efficiency and as little cost as possible. Efforts to monitor the ecosystem for surprises rather than only for product therefore withered in competition with internal organizational needs, and research funds were shifted to more operational purposes. Why monitor or study a success? Thus the gradual reduction of resilience of the ecosystems went unnoticed by any but maverick and suspect academics whose research was driven simply by curiosity.

Success brought changes in the society as well. Dependencies developed and powerful political pressures were exerted for continuing the sustained flow of the food or fiber that no longer fluctuated as it once had. More investments therefore logically flowed to expanding pulp mills, recreational facilities, cattle ranches, and fishing technology. This is the development side of the equation, and its expansion can be rightly applauded. Improving efficiency of agencies should also be applauded. But if the ecosystem from which resources are garnered becomes less and less resilient, more and more sensitive to large-scale transformation, then the efficient but myopic agency and the productive but dependent industry simply become part of the source of crisis and decision gridlock.

So this is the puzzle: The very success in managing a target variable for sustained production of food or fiber apparently leads inevitably to an ultimate pathology of less resilient and more vulnerable ecosystems, more rigid and unresponsive management agencies, and more dependent societies. This seems to define the conditions for gridlock and irretrievable resource collapse. It seems to confirm one opinion that sustainable development is an oxymoron (Ludwig, Hilborn, and Walters 1993). Moreover, those pathologies occur not only in examples of renewable resource management but also in examples of rigid policies of regulation of toxic materials or in examples of narrow implementation of protection for endangered species.

It was this puzzle and its possible solution that set the postulates for the case studies; that is, crisis, conflict, and gridlock emerge whenever the problem and the response have the following characteristics:

- A single target and piecemeal policy.
- A single scale of focus, typically on the short term and the local.
- No realization that all policies are experimental.
- Rigid management with no priority to design interventions as ways to test hypotheses underlying policies.

The pathology continues and deepens when the reaction to conflict is to demand more data or more precision in data (e.g., for defense of lawsuits) and more certainty and more control of information and individuals.

The pathology is broken when the issue is seen as a strategic one of adaptive policy management, of science at the appropriate scales, and of understanding human behavior, not a procedural one of institutional control. This requires

- Integrated policies, not piecemeal ones.
- Flexible, adaptive policies, not rigid, locked-in ones.
- Management and planning for learning, not simply for economic or social product.
- Monitoring designed as a part of active interventions to achieve understanding and to identify remedial response, not monitoring for monitoring's sake.
- Investments in eclectic science, not just in controlled science.
- Citizen involvement and partnership to build "civic science" (Lee 1993), not public information programs to inform passively.

We decided to explore those postulates in a project that would engage an interdisciplinary team whose individuals together represented deep personal experience in specific cases of regional ecosystem analysis and management—people thoroughly grounded in a balance of theory, science, and practice. It was that group that provided the analyses of the case studies and authored the following six chapters. All have a broad range of experience outside their own field of specialization as well as experience with interdisciplinary and integrative modes of inquiry.

Part way through the project we invited another group of individuals active in the development of broad social science theory to join the original team and provide commentary from the perspective of their area of expertise—political science, institutional psychology, institutional management, social learning theory, economics, and Third World development. In addition to providing insight directly to case study authors, four provided commentary chapters for this volume ("Ten Theses on the Promise and Problems of Creative Ecosystem Management in Developing Countries" by Steven E. Sanderson [chapter 8]; "Governing Design: The Management of Social Systems and Ecosystem Management" by Frances Westley [chapter 9]; "Sustainable Development As Social Learning: Theoretical Perspectives and Practical Challenges for the Design of a Research Program" by Edward A. Parson and William C. Clark [chapter 10]; and "Barriers and Bridges to Learning in a Turbulent Human Ecology" by Donald N. Michael [chapter 11]). The full synthesis of this experience in theory and practice then became the focus for the editors, in consultation with the other authors, to prepare the last chapter and develop an expansion of general theory that would explain why the bridges identified succeeded in restoring the degraded renewal capacities of nature and people ("Barriers Broken and Bridges Built: A Synthesis" [chapter 12] by L. H. Gunderson, C. S. Holling, and S. S. Light).

The six cases are all regional-sized systems, and each centers around a recognized ecosystem (figure 1.1). The six systems include (1) maritime portions of the boreal forest and dependent lumbering industry (New Brunswick); (2) an internationally recognized wetland (the Everglades), which supplies fresh water to a burgeoning population, agriculture, and national park; (3) the largest estuarine system in the United States (Chesapeake Bay), with a seemingly sustainable consumption of marine resources; (4) one of the largest river basins in North America (that of the Columbia River), where people struggle to reconcile issues of producing electrical power and salmon; (5) the largest freshwater lake system in North America (the Great Lakes), where two

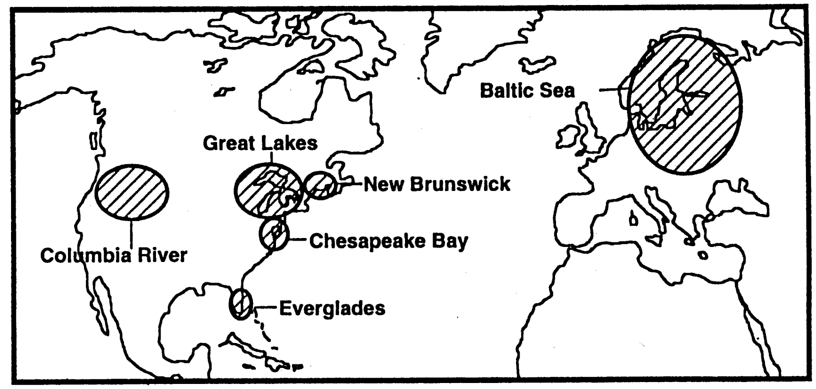

FIGURE 1.1
Location of the six study areas in the world. Ovals approximate the size of each ecosystem.

nations and ten states/provinces develop ways to manage water quality and quantity, fisheries, recreation, and economic opportunities; and (6) the largest brackish sea in the world (the Baltic Sea), surrounded by 15% of the world's industrial production, where nine nations, divided by political ideologies, develop responses to development and environmental deterioration. The case studies are presented in chapters 2–7 in a progression of increasing complexity, defined by the area of the system, population, and number of institutional or management units (table 1.1).

The other major criteria used for selecting the cases involve identifying authors who had a systemwide perspective, were expert in both the ecology and the management of the system, and most important, had lived in the system and participated in policy and management designs. Their individual and collective experience and understanding were tapped for this volume. That growing experience and knowledge have emerged from a pattern of exploitive development that has endured so long because ecosystems are remarkably resilient and because people do learn and adapt.

But the path of learning is not easy, partly because the new class of complex issues is sufficiently novel that the science is incomplete and the future is unpredictable. This is the topic to which I now turn in a search for a direction for understanding.

TABLE 1.1
Area, Population, Population Density and Political Units of Six Study Areas

Study Site	Area* (1000 km²)	Population† (million people)	Population Density (people/km²)	Political Units
New Brunswick	73	0.73	10	1 province
Everglades	23	5.19	224	1 state
Chesapeake	166	14.5	87	6 states
Columbia River	671	9	13	7 states, 2 provinces, 2 nations
Great Lakes	766	38	50	8 states, 2 provinces 2 nations
Baltic Sea	1641	75.2	46	9 nations

*Defined by catchment basin in all systems except New Brunswick.
†Dates of census vary from 1985 to 1990.

Seeking Understanding: Why Scientists Can Muddy the Waters

A critical minority of politicians and of the inquiring public is now not so much driven by fear of prophecies of doom as by the need for understanding. But if you seek understanding, to whom do you turn? Science is not helping, largely because there are not only conflicting voices but conflicting modes of inquiry and criteria for establishing the credibility of a line of argument.

In particular, the philosophies of two streams of science are often in conflict. The tension between them is now particularly evident in biology. One is brilliantly represented by the advances in molecular biology and genetic engineering. That stream of science promises to lead not only to health and economic benefits of biotechnology, but also to an uncertain sea of changing social values and consequences. It is a stream of biology that is essentially experimental, reductionist, and narrowly disciplinary.

The other stream is represented within biology by evolutionary biology and by systems approaches that include the analysis of populations, ecosystems, landscape structures and dynamics, and more recently, biotic and human interactions with planetary dynamics. The applied form of this stream has emerged regionally in new forms of resource and environmental management, where uncertainty and surprises become an integral part of an anticipated set of adaptive responses (Holling 1978; Walters 1986; Lee 1993). It is fundamentally interdisciplinary and combines historical, comparative, and experimental approaches at scales appropriate to the issues. This combination provides the necessary foundations for any kind of global science, if for no other reason than that we have but one globe to live on, for the present, at least, and cannot experimentally manipulate lost pasts. It is a stream of investigation that is fundamentally concerned with integrative modes of inquiry and multiple sources of evidence. This stream has the most natural connection to related ones in the social sciences that are historical, analytical, and integrative. It is also the stream that is most relevant for the needs of policy and politics.

The first stream is a science of parts (e.g., analysis of specific biophysical processes that affect survival, growth, and dispersal of target variables). It emerges from traditions of experimental science, where a narrow enough focus is chosen to pose hypotheses, collect data, and design critical tests for the rejection of invalid hypotheses. The goal is to narrow uncertainty to the point where acceptance of an argument among scientific peers is essentially unanimous. It is appropriately conservative and unambiguous, but it achieves this by being incomplete and fragmentary. It provides bricks for an edifice but not the architectural design.

The other stream is a science of the integration of parts. It uses the results and technologies of the first but identifies gaps, develops alternative hypotheses and multivariate models, and evaluates the integrated consequence of each alternative by using information from planned and unplanned interventions in the whole system that occur or are implemented in nature. Typically, the goal is to reveal the simple causation that often underlies the complexity of time and space behavior of complex systems. Often there is more concern that a useful hypothesis might be rejected than that a false one might be accepted. Since uncertainty is high, the analysis of uncertainty becomes a topic in itself.

The premise of this second stream is that knowledge of the system we deal with is always incomplete. Surprise is inevitable. Not only is the science incomplete, but the system itself is a moving target, evolving because of the impact of management and the progressive expansion of the scale of human influences on the planet.

In principle, therefore, evolving managed ecosystems and the societies with which they are linked involve unknowability and unpredictability. Therefore sustainable development is also inherently unknowable and unpredictable. Therein lies the issue that we address in this book. The essential point is that evolving systems require policies and actions that not only satisfy social objectives but also achieve continually modified understanding of the evolving conditions and provide flexibility for adapting to surprises.

This is the heart of active regional experimentation by management at the scale appropriate to the question—adaptive environmental and resource management (Holling 1978; Walters 1986; Lee 1993). Otherwise the pathologies of exploitive development are inevitable—increasingly brittle ecosystems, rigid management, and dependent societies leading to crises.

Faced with the partial understanding we have of the problems and with the conflicting views of science, it is no wonder that public concern and mistrust are great but public understanding disturbingly bad. Political responses have a weak foundation for confident action that will not make the cure worse than the disease. To whom can the public turn for insight? This is less a problem of trust in science than of trust in governance by all participants who, in the absence of firm foundations for understanding, are forced to shape their decisions by beliefs.

So much presently seems uncertain or unknown that many of the calls for action or inaction, however well supported by technical argument, are largely determined by such beliefs. Because each belief is partially relevant, impressive and convincing technical arguments can be mobilized for each, no matter how conflicting the resulting calls for action or inaction may be.

Four belief systems, and an emerging fifth, are driving present debate and public confusion. Each reflects different assumptions about stability and change, as I have suggested elsewhere (Holling 1987). Alternatively, they can be labeled (albeit unfairly) by a caricature of their causal assumptions, as I shall do here.

The first view (that of Nature Cornucopian) is one of smooth exponential growth where resources are never scarce because human ingenuity always invents substitutes. It was the basic view of Herman Kahn and is the foundation for Julian Simon's arguments (Simon and Kahn 1984). It assumes that humans have an infinite capacity to innovate and that nature changes gradually—fast enough to be detected yet slow enough to be managed.

The second view (that of Nature Anarchic) is hyperbolic, where increase is inevitably followed by decrease. It is a view of fundamental instability, where persistence is only possible in a decentralized system in which there are minimal demands on nature. It is the view of Schumacher (1973) and some extreme environmentalists. If the previous view assumes that infinitely ingenious humans do not need to learn anything different, this view assumes that humans are *incapable* of learning how to deal with the technology they unleash.

The third view (that of Nature Balanced) is one of logistic growth, where the issue is how to navigate a looming and turbulent transition—demographic, economic, social, and environmental—to a sustained plateau. This is the view of several institutions with a mandate for reforming global resource and environmental policy—of the Bruntland Commission, the World Resources Institute, the International Institute of Applied Systems Analysis, and the International Institute for Sustainable Development, for example. Many individuals are contributing skillful scholarship and policy innovation. They are among some of the most effective forces for change.

The fourth view (that of Nature Resilient) is one of nested cycles organized by fundamentally discontinuous events and processes. That is, there are periods of exponential change, of growing stasis and brittleness, of readjustment or collapse, and of reorganization for renewal. Instabilities organize the behaviors as much as stabilities. This was the view of Schumpeter's (1950) economics, and it has more recently been the focus of fruitful scholarship in a wide range of fields—ecological, social, economic, and technical. This has formed the body of my own ecological research for the past 20 years. I find striking similarities in Harvey Brook's view of technology (1986), Brian Arthur's and Kenneth Arrow's (1989) recent view of the economics of innovation and competition (Waldrop 1992), Mary Douglas's (1978) and Mike Thompson's (1983) view of cultures, Don Michael's view of human psychology (1984), and Barbara Tuchman's (1978) and William McNeill's (1979) view of history.

The emerging fifth view (that of Nature Evolving) is evolutionary and adaptive. It has been given recent impetus by the paradoxes that have emerged in successfully applying the previous, more limited views. *Complex systems behavior, discontinuous change, chaos and order, self-organization, nonlinear system behavior, and adaptive evolving systems* are all the present code words characterizing the more recent activities. This view is leading to integrative studies that combine insights and people from developmental biology and genetics, evolutionary biology, physics, economics, ecology, and computer science. The Santa Fe Institute is an interesting experiment (Waldrop 1992) in applying collaborative approaches to explore the insights and opportunities opened by such an evolutionary paradigm.

The point is not that one of these beliefs is correct and the others wrong. Each is true, but each is a partial truth. Because we are only now beginning to understand the changing reality, there is no limit to the ability of a good scientist to invent compelling lines of causal explanation that inexorably support his or her particular beliefs. How can even the best-intentioned politician possibly be expected to deal with that? How can even the most reflective citizen? With every issue having supporting evidence and contradictory counterevidence (all legitimate), the issues seem to involve no independent reality of nature, only moral issues that can be debated. Can we ever separate belief from fact?

Foundations for Integration: Science, Understanding, and Policy

The preceding argument explains my unease with calls for action that are dominated exclusively by prophesies of crisis. Certainly it is appropriate to cite clear examples of the critical new class of problems, particularly those that clarify the need for action (e.g., AIDS, the hole in the ozone layer, and carbon dioxide increase). These are so clear, so growing, so global, and so novel that action can be taken, which we would want to do in any case for other reasons of efficiency, health, and economic sustainability.

Perhaps I have been in the game too long to be sympathetic to "Chicken Little" stories of catastrophe. In 1969 *Time* magazine entitled an article "The New Jeremiahs" and featured six scientists who were prophesying doom—an environmental doom that may have been novel then but that is familiar now. I remember they included Paul Ehrlich, Barry Commoner, Ken Watt, and—me! Now, 25 years later, I find the articles, projects, and proposals that repeat the same litany of doom to be not necessarily wrong, but tiresome, unconvincing, and weak.

But what is really disturbing is that they ignore the remarkable advances, learning, and understanding that have occurred in the intervening years. They ignore the opportunities for conversation among and actions by previously polarized individuals that increase both understanding and the ability to develop and apply integrated and adaptive policies. The problems and topics revolve around five interrelated themes—regional resource management and development, ecosystem restoration, sustainable development, global change, and biodiversity. Population growth and technology drive them all.

The last 20 years have seen a stunning advance in understanding how the planet has evolved and functions in its physical aspects. The reconstruction of the composition of our atmosphere over the last 160,000 years (using bubbles trapped in the Vostok ice core from Antarctica) and its correlation with climate (using proxy biological and chemical signals) can be seen as an engrossing tour de force of international science. It is also useful for politicians. It tells them that the present concentration of carbon dioxide in our atmosphere is higher than it has been for the last 160,000 years.

The detection of the ozone hole in the Antarctic came as a complete surprise to existing "gradualist" theories of the atmosphere, and the demonstration of its reality and of the role of industrial emissions of chlorofluorocarbons on atmospheric chemistry has been an example of the passionate application of the best kind of cooperative, and at times combative, science in a complex new area. This has also been useful for politicians, as countries now move to ban CFCs as an act of international cooperation.

However narrow the mainstream of molecular biology might be, it has yielded techniques that now are transforming the evolutionary, ecological, and conservation sciences. Is it true that we can trace all human mitochondrial DNA back to an "Eve" in Africa (Vigiland et al. 1991)? Biologists now can certainly unravel affinities in related groups of species and individuals and can join the geophysicists in compelling reconstructions of the past that, at the least, put our present problems in a perspective—from the role of past extinctions to present declines in biodiversity.

The understanding needed for the changes we now experience or anticipate draws on this knowledge from geophysics, atmospheric science, and techniques of cellular and molecular biology. However, to understand such changes we must integrate ecosystem and community ecology with the more physically based earth sciences.

But we must recognize what this means and the challenge it presents. The relevant biophysical processes operate over an enormous scale, potentially from soil processes operating with time constants of hours or days in meter-square patches, to ecosystem successional processes of decades to centuries covering tens to thousands of square kilometers, to global biotic processes involved in the regulation and isolation of elements like carbon, which have time lags of millennia and a global impact. This is why satellite imagery, remote sensing, and geographic information systems now routinely available to analyze patterns are of such major consequence. Computer advances, both toward the portable but powerful and the large and parallel, have made it possible to visualize complexity in both space and time. It is a picture of discontinuous behavior, of multiple stable states, of the interaction between slow forces that accumulate environmental capital and fast processes that slowly exploit, suddenly release, and renew the capital. It is as far a cry from public perceptions of fragile, stable, and equilibrium nature as could be imagined. And that knowledge too is useful and used. It is the foundation for the regional experiments in adaptive policy design and management that are as much examples of institutional learning as they are of using science for public policy.

Moreover, emerging theories of hierarchical structure, of scale-independent geometry, and of nonlinear dynamics are providing the focus for posing the researchable questions about cross-scale interactions that are the first step toward usable understanding and useful policy. This is the topic to which I shall now turn.

On Theory

"Don't give me academic theory; give me practical advice and actions!" That's what I heard, appropriately, in the certainty of the 1970s. But at a time of confusion, such as the 1990s, promising and relevant theory is the only antidote to dated ideology or belief. And the intriguing paradoxes that have emerged by applying past incomplete theory of equilibrium, of gradual change, and of control have set a foundation for new theories of discontinuous change and evolution. Oddly, one of the most practical things we could recommend now is massive support for the expansion of new theory, but in combination with synthesizing theory from the reality of examples. An inductively based expansion of theory has the promise of yielding both integrated understanding and integrated actions.

The intensity and global nature of the changes now taking place are moving the planet and its occupants into totally new behavior. In this transformation some consequences can be predicted, others will be uncertain, and still others will be unpredictable. As a consequence, it is

essential to be guided by theories of change that can contain short- and long-term changes, gradual and abrupt ones, and dynamic and structural ones.

These theories determine the questions we ask, the problems we perceive, the data we collect and analyze, and the policies and actions we initiate. Theories that do not match the problem can be at best delusions and at worst dangerous.

The discovery of the hole in the ozone layer is an example of the former. It was not detected initially by satellite imagery, because the smoothing algorithm applied to the data assumed that abrupt changes could only be caused by instrument glitches. The implicit theory presumed gradual, continuous change in atmospheric chemistry and chemical composition.

There are also many examples of theories that have had more disastrous consequences. The devastating events in the Sahel of Africa is one recent example, as Brian Walker and Tony Sinclair have described (1990). External changes in precipitation were partially responsible for the collapse in the region, but such changes have occurred and been absorbed before. The response was exaggerated by increased vulnerability of a culture and ecosystem caused in part by development aid that broke the patterns of nomadic movement and social adaptation that had evolved in these semiarid savannas. No adequate theory was utilized to relate the resilience of local ecosystems and the adaptive flexibility of people to mesoscale migrations of people and animals.

Regional changes of this nature and the anticipated global ones make the world we are entering one of surprises whose consequences threaten to overwhelm the adaptive capacities of individuals, business, and government. Investing in the development and testing of usable and useful theory is therefore not an academic luxury, but a practical necessity, particularly at times of such profound change.

The issue is not only one of change in general, but one of evolutionary change. The conceptual foundations therefore need to be drawn from the growing experience in understanding the operation of complex, nonlinear systems where discontinuous behavior and structural change are the norm. Scholars in an unusual variety of disciplines have contributed to the development of these theories—from thermodynamics (Nicolis and Prigogine 1977), oceanography (Broeker), climatology (Lorenz 1963), atmospheric chemistry (Crutzen and Arnold 1986), evolutionary and developmental biology (Kauffman 1992), and ecology (May 1977; Levin 1992; and my own work). All deal with the reality of abrupt changes organized by several equilibria, of the existence of multistable states, and of the interplay between order and disorder in evolving self-organizing systems. This is what our world is, and it is at the heart of feasible sustainable development.

Social scientists are also major contributors. Such historians as William McNeill (1979) have long argued in favor of a view of history that is a sequence of discontinuous events and of human responses to them. Wildavsky and Douglas (1982) argue for the inevitability and need for risk and surprise in any human development. More recently, Mary Douglas (1978) and Mike Thompson (1983) have used their background in cultural anthropology to characterize institutions as being driven by a similar interplay between stability and instability. And when someone of the stature of Kenneth Arrow suggests the need for transforming economics by nonlinear theory (as quoted in Waldrop 1992), a revolution in thought may be occurring in that field as well. In every instance these theories owe their force to the resolution of puzzles that appear when earlier incomplete or inadequate concepts encounter surprising reality.

The way key subcultures in the natural and social sciences view the world is converging on these theories of change. These theories rationalize the paradoxes of stability and instability, of order and disorder, and of stasis and evolutionary change. Since these are the same paradoxes inherent in the goal of sustainability and development, an avenue opens for directly relevant cooperation between critical parts of the social and natural sciences.

As a start, I shall describe this view of change as it applies to ecological systems. I do so not to force an inappropriate analogy on the way social and economic systems function, but to search for the common foundations for change that underlie the operation of any complex living system.

Ecosystem Function

Over the last decade, the literature on ecosystems has led to major revisions in a view of succession that was proposed by Clements early in this century (1916). That view was one of a highly ordered sequence of species assemblages moving toward a sustained climax whose characteristics are determined by climate and edaphic conditions. This revision comes from extensive comparative field studies (West et al. 1981), from critical experimental manipulations of watersheds (Bormann and Likens

1981; Vitousek and Matson 1984), from paleoecological reconstruction (Davis 1986; Delcourt et al. 1983), and from studies that link systems models and field research (West et al. 1981).

The revisions include four principal points. First, the species that invade after disturbance and during succession can be highly variable and determined by chance events. Second, both early and late successional species can be present continuously. Third, large and small disturbances triggered by such events as fire, wind, and herbivores are an inherent part of the internal dynamics and in many cases set the timing of successional cycles. Fourth, some disturbances can carry the ecosystem into quite different stability domains—mixed grass and tree savannas into shrub-dominated semideserts, for example (Walker 1981); thus there is more than one possible "climax" state.

In summary, therefore, the notion of a sustained climax is a useful but essentially static and incomplete equilibrium view. The combination of these advances in ecosystem understanding with studies of population systems has led to one version of a synthesis that emphasizes four primary stages in an ecosystem cycle (Holling 1986).

The traditional view of ecosystem succession has been usefully seen as being controlled by two functions: *exploitation,* in which rapid colonization of recently disturbed areas is emphasized, and *conservation,* in which slow accumulation and storage of energy and material are emphasized. For an economy, an economist might use such labels as *market* and *innovation* for the exploitation phase and *monopolist* or *hierarchy* for the conservation phase.

But the revisions in understanding indicate that two additional functions are needed (figure 1.2). One is that of *release,* or *creative destruction,* a term borrowed from the economist Schumpeter (as reviewed in Elliott 1980), in which the tightly bound accumulation of biomass and nutrients becomes increasingly fragile (overconnected, in systems terms) until it is suddenly released by agents such as forest fires, insect pests, or intense pulses of grazing. The second is one of *reorganization,* in which soil processes of mobilization and immobilization minimize nutrient loss and reorganize nutrients to become available for the next phase of exploitation. An economist might use such labels as *invention* and *reinvestment* for this stage.

During this cycle, biological time flows unevenly. The progression in the ecosystem cycle proceeds from the exploitation phase (box 1, figure 1.2), slowly to conservation (box 2), very rapidly to release (box 3), rapidly to reorganization (box 4), and rapidly back to exploitation. Dur-

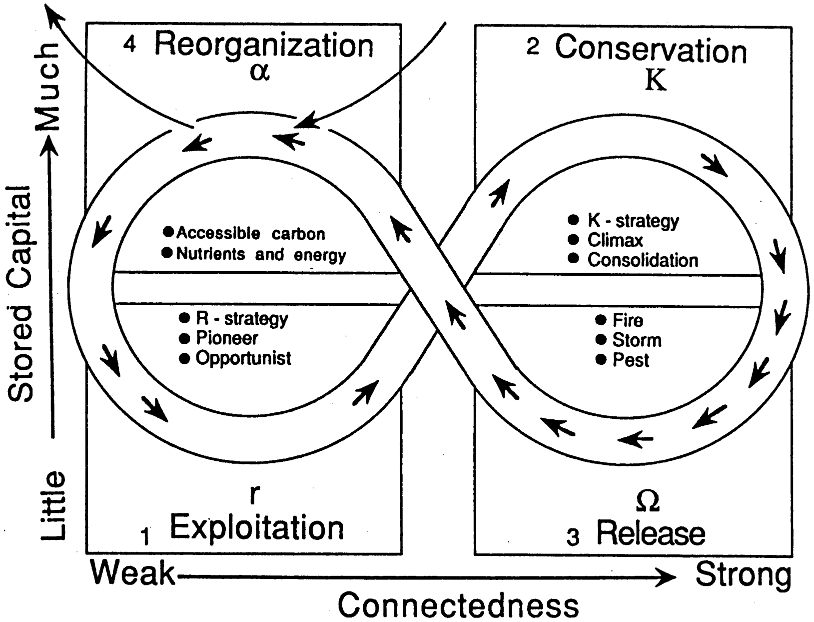

FIGURE 1.2

The four ecosystem functions and the flow of events between them. The arrows show the speed of that flow in the ecosystem cycle, where arrows close to each other indicate a rapidly changing situation and arrows far from each other indicate a slowly changing situation. The cycle reflects changes in two attributes; that is: (1) the *Y* axis—the amount of accumulated capital (nutrients, carbon) stored in variables that are the dominant keystone variables at the moment—and (2) the *X* axis—the degree of connectedness among variables. The exit from the cycle indicated at the left of the figure suggests the stage where a flip is most likely into a less or more productive and organized system (i.e., devolution or evolution as revolution!).

ing the slow sequence from exploitation to conservation, connectedness and stability increase and a "capital" of nutrients and biomass is slowly accumulated. That capital becomes more and more tightly bound, preventing other competitors from utilizing the accumulated capital until the system eventually becomes so overconnected that rapid change is triggered. The agents of disturbance might be wind, fire, disease, insect outbreak, or a combination of these. The stored capital is then suddenly released and the tight organization is lost to allow the released capital to be reorganized to initiate the cycle again.

This pattern is discontinuous and depends on changing multistable states to trigger and organize the release and reorganization functions. Instabilities and chaotic behavior trigger the release phase, which then

proceeds in the reorganization phase, where stability begins to be reestablished. In short, chaos emerges from order, and order emerges from chaos! Resilience and recovery are determined by the fast release (or creative destruction) and reorganization sequence, whereas stability and productivity are determined by the slow exploitation and conservation sequence.

Moreover, there is a nested set of such cycles, each with its own range of scales. In the typical boreal forest, for example, fresh needles cycle yearly; the crown of foliage cycles with a decadal period; and trees, gaps, and stands cycle at a period of about a century or more. The result is a hierarchy in which each level has its own distinct spatial and temporal attributes (figure 1.3).

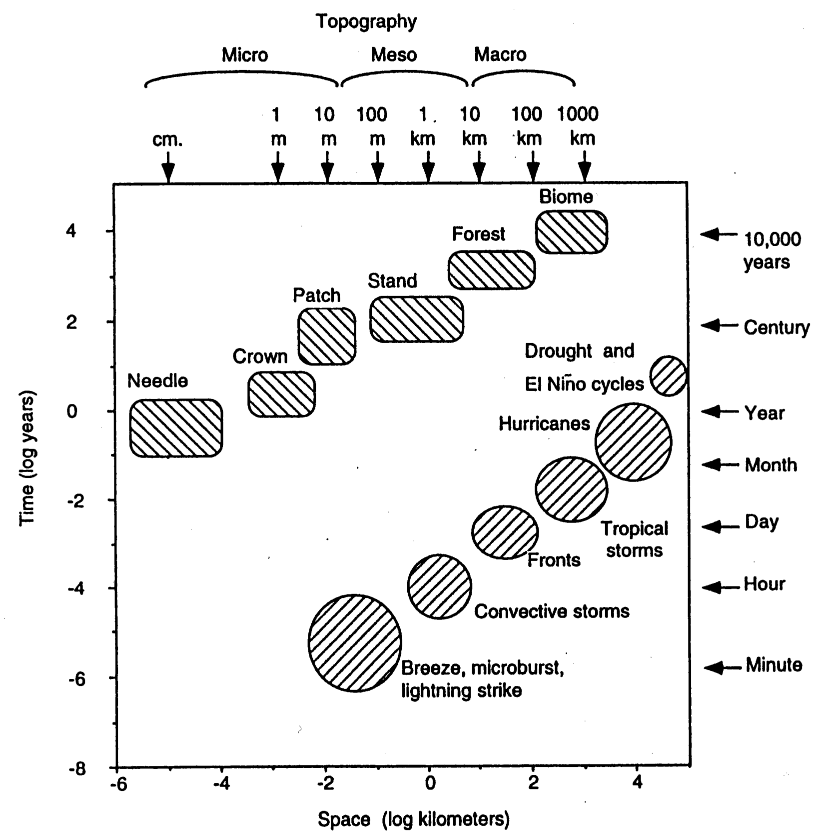

FIGURE 1.3

Space/time hierarchy of the boreal forest and of atmosphere.

Dynamics of Hierarchies

A critical feature of such hierarchies is the asymmetric interactions between levels (Allen and Starr 1982; O'Neill et al. 1986). In particular, the larger, slower levels maintain constraints within which faster levels operate. In that sense, therefore, slower levels control faster ones. If that is the only asymmetry, however, it would be impossible for organisms to exert control over slower environmental variables. This is the criticism that many geologists make of the Gaia theory (Lovelock 1988): How could slow geomorphic processes possibly be affected by fast biological ones? However, it is not broadly recognized that the birth, growth, death, and renewal cycle, shown in figure 1.2, transforms hierarchies from fixed static structures to dynamic entities whose levels are vulnerable to small disturbances at certain critical times in the cycle (Holling 1992). That represents a transient but important bottom-up asymmetry.

There are two key states where slower and larger levels in ecosystems become briefly vulnerable to dramatic transformation because of small events and fast processes. One is when the system becomes overconnected and brittle as it slowly moves toward maturity (box 2, figure 1.2). At these stages, there are tight competitive relations among the plant species. From an equilibrium perspective, the system is highly stable (i.e., fast return times in the face of small disturbances), but from a resilience perspective, *sensu* Holling (1987), the domain over which stabilizing forces can operate becomes increasingly small. Vulnerability comes from such loss of resilience. Hence the system becomes an accident waiting to happen. In the boreal forest, for example, the accident might be a contagious fire that becomes increasingly likely as the amount, extent, and flammability of fuel accumulates. Or it could be a spreading insect outbreak triggered as increasing amounts of foliage both increase food and habitat for defoliating insects and decrease the efficiency of search by their vertebrate predators (Holling 1988). It is also the phase where, in human organizations, the rebellion of aggressive interest groups can precipitate an inexorable demand for change.

Small and fast variables can also dominate slow and large ones at the stage of reorganization (box 4, figure 1.2). At this stage the system is underconnected, with weak organization and weak regulation. As a consequence, it is the stage most affected by probabilistic events that allow a diversity of entrained species, as well as exotic invaders, to become established. On the one hand, it is the stage most vulnerable to erosion and to the loss of accumulated capital. On the other hand, it is the stage from which jumps to unexpectedly different and more productive systems are possible. At this stage, instability comes because of loss of regulation rather than from the brittleness of reduced resilience. It is the phase in a system—ecological or human—where the individual or small groups of individuals can make the greatest structural change for the future.

It is this view of alternative phases in a cycle of birth, growth, death, and renewal that seems to underlie any complex adaptive system—ecological certainly, but human, institutional, and societal as well. This is one of the proposed foundations to the synthesis we explore in this book. Does such a view have generality? Does it suggest what to do, and equally important, what not to do? If so, then a possible foundation exists to turn sustainable development from an oxymoron to a plan of action.

The Paradox of Sustainable Development

Sustainable development is itself something of a paradox. The phrase implies that something must change but that something must also remain constant. The paradox appears in a number of forms, and its resolution can provide the direction to seek for investments that could sustain development.

In the introduction I described the two puzzles that appeared when I reviewed several examples of managed ecosystems. One concerned the organization of ecosystems. The other concerned the management of ecosystems. Both have turned out to be the consequence of the natural workings of any complex, evolving system. The resolution of those puzzles is central to the way ecosystems can be restored within a regional context of social and economic activities.

As described previously in this chapter, the first puzzle suggested that the great diversity of life in ecosystems is traceable to the function of a small set of variables, each operating at a qualitatively different speed from the others. The second puzzle suggested that any attempt to manage ecological variables inexorably led to less resilient ecosystems, more rigid management institutions, and more dependent societies. It was this puzzle, more than any, that launched this book's effort to compare regional experiences. I will now review each in turn, in order to show how the previous section on theories of change relates directly to the sustainability of development.

The Ecosystem Organization Puzzle

How could the great diversity within ecosystems possibly be traced to the function of a small number of variables? The models that were developed and tested for these examples certainly generated complex behavior in space and time. Moreover, those complexities could be traced to the actions and interactions of only three or four sets of variables and associated processes, each of which operated at distinctly different speeds. The speeds were therefore discontinuously distributed and differed from their neighbors, often by as much as an order of magnitude. A summary of the critical structuring variables and their speeds is presented in table 1.2. For the models at least, this structure organizes the time and space behavior of variables into a small number of cycles, presumably abstracted from a larger set, that continue at smaller and larger scales than the range selected.

But are those features simply the consequence of the way modelers make decisions, rather than the results of ecosystem organization? This uneasy feeling that such conclusions can be a contrivance of our minds rather than a reflection of the way ecosystems actually function led to a series of tests using field data to challenge the hypothesis that ecosystem dynamics are organized around the operation of a small number of nested cycles, each driven by a few dominant variables (Holling 1992).

The critical argument is that if there are, in fact, only a few structuring processes, their imprint should be expressed on most variables. That is, time series data for fires; seeding intensity; insect, mammal, and bird numbers; water flow (indeed, any variable for which there are long-term, yearly records) should show periodicities that cluster around a few dominant ones. In the case of the eastern maritime boreal forest of North America, for example, those periodicities were predicted to be 3–5 years, 10–15 years, 35–40 years, and more than 80 years. Similarly, there should be a few dominant spatial "footprint" sizes, each associated with one of the disturbance/renewal cycles in the nested set of such cycles. Finally, the animals living in specific landscapes should demonstrate the existence of this lumpy architecture by showing gaps in the distribution of their sizes and gaps in the scales at which decisions are made for location of region, foraging area, habitat, nests, protection, and food.

All the evidence we have so far confirms just those hypotheses—for boreal forests, boreal region prairies, pelagic ecosystems (Holling 1992),

TABLE 1.2
Key Variables and Speeds in Four Groups of Managed Ecosystems

The System	Fast Variable	Intermediate Variable	Slow Variable	Key Reference
Forest insect	Insect, needles	Foliage, crown	Trees	McNamee et al. (1981), Holling (1991)
Forest fire	Intensity	Fuel	Trees	Holling (1980)
Savanna	Annual grasses	Perennial grasses	Shrubs	Walker et al. (1969)
Aquatic	Phytoplankton	Zooplankton	Fish	Steele (1985)

and the Everglades of Florida (Gunderson 1992). A variety of alternative hypotheses based on developmental, historical, or trophic arguments was disproved in the fine traditions of Popperian science, leaving only the "world-is-lumpy" hypothesis as resisting disproof.

I conclude therefore that there is strong evidence for the following:

1. A small number of plant, animal, and abiotic processes structure biomes over scales from days and centimeters to millennia and thousands of kilometers. Individual plant and biogeochemical processes dominate at fine, fast scales; animal and abiotic processes of mesoscale disturbance dominate at intermediate scales; and geomorphological ones dominate at coarse, slow scales.
2. These structuring processes produce a landscape that has lumpy geometry and lumpy temporal frequencies or periodicities. That is, the physical architecture and the speed of variables are organized into distinct clusters, each of which is controlled by one small set of structuring processes. These processes organize behavior as a nested hierarchy of cycles of slow production and growth alternating with fast disturbance and renewal.
3. Each cluster is contained within a particular range of scales in space and time and has its own distinct architecture of object sizes, interobject distances, and fractal dimensions within that range.
4. All the many remaining variables, other than those involved in the structuring processes, become entrained by the critical

structuring variables, so that the great diversity of species in ecosystems can be traced to the function of a small set of variables and the niches they provide. The structuring processes both form structure and are affected by that structure. These structuring variables are therefore where the priority should be placed in investing to renew, maintain, or restore ecosystems.

5. The discontinuities that produce the lumpy structure of vegetated landscapes impose discontinuities on the behavior and morphology of animals. For example, there are gaps in body mass distributions of resident species of animals that correlate with scale-dependent discontinuities in the geometry of vegetated landscapes. Thus these gaps, and the body mass clumps they define, become a way to develop a rapid bioassay of ecosystem structures and of human impacts on that structure. It therefore opens the way to develop a comparative ecology across scales that might provide the same power for generalization that came when physiology became comparative rather than species specific.
6. Conversely, changes in landscape structure at defined scale ranges caused by land use practice or by climate change will have predictable impacts on animal community structure (e.g., animals of some body masses can disappear if an ecosystem structure at a predictable scale range is changed). Therefore predicted (from models or land use plans) or observed (from remote imagery) impacts of changing climate or land use on vegetation can also be used to infer the impacts on the diversity of animal communities.

The lessons for both sustainable development and biodiversity loss are clear: Focus should be on the structuring variables that control the lumpy geometry and lumpy time dynamics. They set the stage upon which other variables play out their own dramas. That is, it is the physical and temporal infrastructure of biomes *at all scales* that sustains the theater; given that, the actors will look after themselves!

The Ecosystem Management Puzzle

Earlier I identified a puzzle that launched the studies in this book. In many cases of renewable resource management, success in managing a target variable for sustained production of food or fiber apparently leads

to an ultimate pathology of less resilient and more vulnerable ecosystems, more rigid and unresponsive management agencies, and more dependent societies. But something seems to be wrong with that conclusion, which implies that the only solution for humanity is a radical return to being "children of nature." The puzzle needs to be clarified in order to test its significance and generality.

The conclusion is based on two critical points. One is that reducing the variability of ecosystems inevitably leads to reduced resilience and increased vulnerability. The second is that there is no other way for agencies and people to manage and benefit from resource development.

Again some independent evidence is needed. Are there counterexamples? Oddly, nature itself provides counterexamples of tightly regulated yet sustainable systems in the many examples of physiological homeostasis. Consider temperature regulation of endotherms ("warm-blooded" animals), for example. That represents a system where internal body temperature is not only tightly regulated within a narrow band, but among present-day birds and mammals, at an average temperature perilously close to lethal. Moreover, that regulation requires ten times more energy for metabolism than is required by an ectotherm. This would seem to be a recipe for disaster, and a very inefficient one at that. Yet evolution somehow led to the extraordinary success of those with such an adaptation—the birds and mammals.

To test the generality of the variability loss/resilience loss hypothesis, I have been collecting data from the physiological literature on the viable temperature range of the internal body of organisms exposed to different classes of variability. I have organized the data into three groups, ranging from terrestrial ectotherms ("cold-blooded" animals) exposed to the greatest variability of temperature from unbuffered ambient conditions, to aquatic endotherms exposed to an intermediate level of variability because of the moderating attributes of water, to endotherms that regulate temperature within a narrow band. The viable range of internal body temperature decreases from about 40°C for the most variable group to about 30°C for the intermediate, to 20°C for the tightly regulated endotherms. Resilience (in this case the range of internal temperatures that separates life from death) clearly does contract as experience with variability is reduced, just as in the resource management cases. I conclude, therefore, that reduction of variability of living systems from organisms to ecosystems inevitably leads to loss of resilience in that part of the system being regulated.

But that seems to leave an even starker paradox of control inevitably leading to collapse. But, in fact, endothermy does persist. It therefore serves as a revealing metaphor for sustainable development. This metaphor contains two features that were not evident in my earlier descriptions of examples of resource management.

First, the kind of regulation is different. Five different mechanisms, from evaporative cooling to metabolic heat generation, control the temperature of endotherms. Each mechanism is not notably efficient by itself. Each operates over a somewhat different range of conditions and with different efficiencies of response. This overlapping "soft" redundancy seems to characterize biological regulation of all kinds. It is not notably efficient or elegant in the engineering sense. But it is robust and continually sensitive to changes in internal body temperature. This is quite unlike the examples of rigid regulation by management where goals of operational efficiency gradually isolated the regulating agency from what it was regulating.

Second, endothermy is a true innovation that explosively released opportunity for the organisms evolving the ability. Maintaining high body temperature, short of death, allows the greatest range of external activity for an animal. Speed and stamina increase and activity can be maintained at both high and low external temperatures. A range of habitats forbidden to an ectotherm is open to an endotherm. The evolutionary consequence of temperature regulation was to open opportunity suddenly for dramatic organizational change and the adaptive radiation of new life forms. Variability is therefore not eliminated. It is reduced in one place and transferred from the animal's internal environment to its external one as a consequence of allowing continual probes by the whole animal for opportunity and change. Hence the price of reducing internal resilience and maintaining high metabolic levels is more than offset by that creation of evolutionary opportunity.

That surely is at the heart of sustainable development—the release of human opportunity. It requires flexible, diverse, and redundant regulation, monitoring that leads to corrective responses, and experimental probing of the continually changing reality of the external world. Those are the features of adaptive environmental and resource management. Those are the features missing in the descriptions I presented of traditional, piecemeal, exploitive resource management and its ultimate pathology.

The case studies presented here have shown that the descriptions and postulates that launched this effort are seriously incomplete. For example, in New Brunswick, the intensifying gridlock in forest management, combined with slowly accumulated and communicated understanding, led to an abrupt transformation of policy whose attributes became much like those just described for homeostasis (Baskerville, chapter 2). It is a policy that functions for a whole region by transforming and monitoring the smaller-scale stand architecture of the landscape and by releasing the productive and innovative capacities of industry.

Even though the postulates are incomplete, they did provide the direction to reveal a number of new insights in the case studies. Informal collegia with contacts inside (rebel bureaucrats) and outside (maverick academics) the system are necessary to unlocking institutional gridlock, as is the case with New Brunswick, the Everglades (Light et al., chapter 3), and the Baltic (Jansson and Velner, chapter 7). The development of a sense of involvement, ownership, and belonging by the people at a regional scale was important to the generation of sustainable policies in the Chesapeake Bay (Costanza and Greer, chapter 4) and Great Lakes (Francis and Regier, chapter 6). An institution charged with regional strategic planning and supported by a research arm seems essential to provide that integrative and long-term view that is inexorably lost in agencies with a primary management or regulatory function (Lee, chapter 5). These and other conclusions are described in the concluding synthesis chapter.

These examples of regional resource management do suggest that institutions and societies achieve periodic advances in understanding and learning through the same four cycles of growth, production, release, and renewal that shape the spatial and temporal dynamics of ecosystems (figure 1.2). But each proceeds at its own pace and in its own space, and this creates extraordinary conflicts when there are extreme mismatches among the scales at which ecosystems, institutions, and societies function. If the scale of all three become more congruent, it is likely that the inevitable bursts of human learning can proceed with less conflict and more creativity.

This chapter has used metaphors and puzzles to provide some insight into what sustainable development is and how to harmonize relationships among people, nature, and enterprise. The ecosystem metaphor led to the conclusion that there is a cycle of slow growth and production that triggers fast disturbance and renewal. The slow growth and production phase accumulates natural capital. It is analogous to the processes of what we call development.

The fast disturbance and renewal phase releases bound and constrained capital and reorganizes it for a reestablishment of the ecosystem cycle. It is analogous to the conditions of what we call sustainability, and it is the phase where diversity is maintained. Therefore sustainability is measured by some attributes of disturbance and renewal, and development is measured by some attributes of growth and production.

The solution of a puzzle of ecosystem organization helped clarify what the specific attributes are that determine ecosystem sustainability. The puzzle was that a few simple processes seem to generate the great complexity and diversity within ecosystems. Ecosystems are hierarchically structured into a number of levels. Relatively few processes determine this structure, and each imposes distinct frequencies in space and time on the ecosystem over different scale ranges. They entrain all other variables.

Hence both sustainability and biodiversity are determined by the structuring variables of disturbance and renewal that control the lumpy geometry and lumpy time dynamics. To use another metaphor, they set the stage upon which other variables play out their own dramas. The health and viability of the physical and temporal infrastructure of biomes *at all scales* sustain the theater. Given that, the actors will look after themselves!

A second puzzle suggested that many existing examples of management of renewable resources inexorably led to more vulnerable ecosystems, more rigid management institutions, and more dependent societies. Its resolution came from another biological metaphor of regulation, that of homeostatic regulation of body temperature in endotherms. Indeed, successful control of variability there does reduce resilience within the system regulated. Unlike the pathology of management noted, however, the regulation is responsive to internal change and is functionally diverse and robust. It transfers internal variability externally to release opportunity for probing, creative opportunities.

This is at the heart of sustainable development—the release of human opportunity. It requires flexible, diverse, and redundant regulation; monitoring that leads to corrective responses; and experimental probing of the continually changing reality of the external world.

Finally, sustainable development is neither an ecological problem, a social problem, nor an economic problem. It is an integrated combination of all three. Effective investments in sustainable development therefore simultaneously retain and encourage the adaptive capabilities of people, business enterprises, and nature. The effectiveness of those adaptive capabilities can turn the same unexpected event (e.g., drought, price change, market shifts) into an opportunity for one system, or a crisis for another. These adaptive capacities depend on the processes that permit renewal in society, economies, and ecosystems. For nature it is biosphere structure; for businesses and people it is usable knowledge; and for society as a whole it is trust.

Citizen and politician are now frustrated because they are not hearing simple and consistent answers to the following key questions about present environmental and renewable resource issues:

- What is going to happen under what conditions?
- When will it happen?
- Where will it happen?
- Who will be affected ?
- How uncertain are we?

The answers are not simple or consistent because we have just begun to develop the concepts, technology, and methods that can deal with the generic nature of the problems. These generic features can be described in various ways, but here is my overly academic attempt:

- The problems are essentially systems problems where aspects of behavior are complex and unpredictable and where causes, although at times simple (when finally understood), are always multiple. *Therefore interdisciplinary and integrated modes of inquiry are needed for understanding. And understanding (not complete explanation) is needed to form policies.*
- The problems have a fundamentally nonlinear cause. They demonstrate multistable states and discontinuous behavior in both time and space. *Therefore the concepts that are useful come from nonlinear dynamics and theories of complex systems. Policies that rely exclusively on social or economic adaptation to smoothly changing and reversible conditions lead to reduced options, limited potential, and perpetual surprise.*
- The problems are increasingly caused by slow changes, reflecting decadal accumulations of human influences on air and oceans and decadal to centurial transformations of landscapes. These slow changes cause sudden changes in fast environmental variables that directly affect the health of people, productivity of renewable resources, and vitality of societies. *Therefore analysis should focus on the interactions between slow phenomena and fast ones, and monitoring should focus on long-*

term, slow changes in structural variables. The political window that drives quick fixes for quick solutions simply leads to more unforgiving conditions for decisions, more fragile natural systems, and more dependent and distrustful citizens.

- The spatial span of connections is widening, so that the problems are now fundamentally cross-scale in both space and time. National environmental problems can now more and more frequently have their source both at home and half a world away (witness greenhouse gas accumulations, the hole in the ozone layer, AIDS, and narrowing biodiversity). Natural planetary processes mediating these issues are coupling with the human, economic, and trade linkages that have evolved among nations since World War II. *Therefore the science needed is not only interdisciplinary but cross-scale. Yet the very best environmental and ecological research and models have achieved their success by being either scale independent or constrained to a narrow range of scales. Hierarchical theory, spatial dynamics, event models, satellite imagery, and parallel processing may open new ways to violate, successfully, the hard-won experience of the best ecosystem modelers (i.e., never include more than two orders of magnitude; otherwise the models will be smothered by detail).*
- Both the ecological and social components of these problems have an evolutionary character. That is why the phrase *sustainable development* is not an oxymoron. The problems are therefore not amenable to solutions based on knowledge of small parts of the whole or on assumptions of constancy or stability of fundamental relationships—ecological, economic, or social. Assumptions that such constancy is the rule might give a comfortable sense of certainty, but it is spurious. Such assumptions produce policies and science that contribute to a pathology of rigid and unseeing institutions, increasingly vulnerable natural systems, and public dependencies. *Therefore the focus best suited for the natural science components is evolutionary, that for economics and organizational theory is learning and innovation, and that for policies is actively adaptive designs that yield understanding as much as they do product.*

Part 2

Case Studies

5

Deliberately Seeking Sustainability in the Columbia River Basin

Kai N. Lee

To succeed, sustainable development must originate in political choice and be carried into institutional transformation. This chapter explores the question of weaving sustainability into the institutional fabric of a large ecosystem, the Columbia River Basin in the Pacific Northwest region of the United States. Crises in that region's political economy in the 1970s have prompted an ambitious attempt to rebuild salmon populations in the midst of the largest hydropower system in the world. An institutional structure that realigns but does not supersede existing authorities is emerging, together with a shared perception of the possibilities and conflicts implicit in managing resources whose requirements are partly incompatible. The goal is an ecologically sustainable salmon population coexisting with an economically sustainable hydropower system. An optimist sees in the still incomplete story of the Columbia basin a social system searching for a path to that goal of dual sustainability; a pessimist sees resistance to the changes needed before sustainability can be realized.[1] This chapter takes the view of an analyst looking for larger lessons from a case pregnant with possibilities.

Rising in the Canadian Rocky Mountains and flowing 1200 miles through the Pacific Northwest, the Columbia is the fourth largest river in North America, draining an area that includes parts of seven U.S.

states and two Canadian provinces (figure 5.1). The river's average annual stream flow of 141 million acre-ft is more than ten times that of the Colorado (Kahrl 1978). The Columbia's high flows and extensive drainage have made it ideal for colonization, first, by fish and wildlife (Wilkinson and Conner 1983), as the glaciers retreated at the end of the last ice age and, much later, by dam-building humans.

Well into the nineteenth century the Columbia River Basin was a wilderness. Because it is a major spawning ground and nursery of the

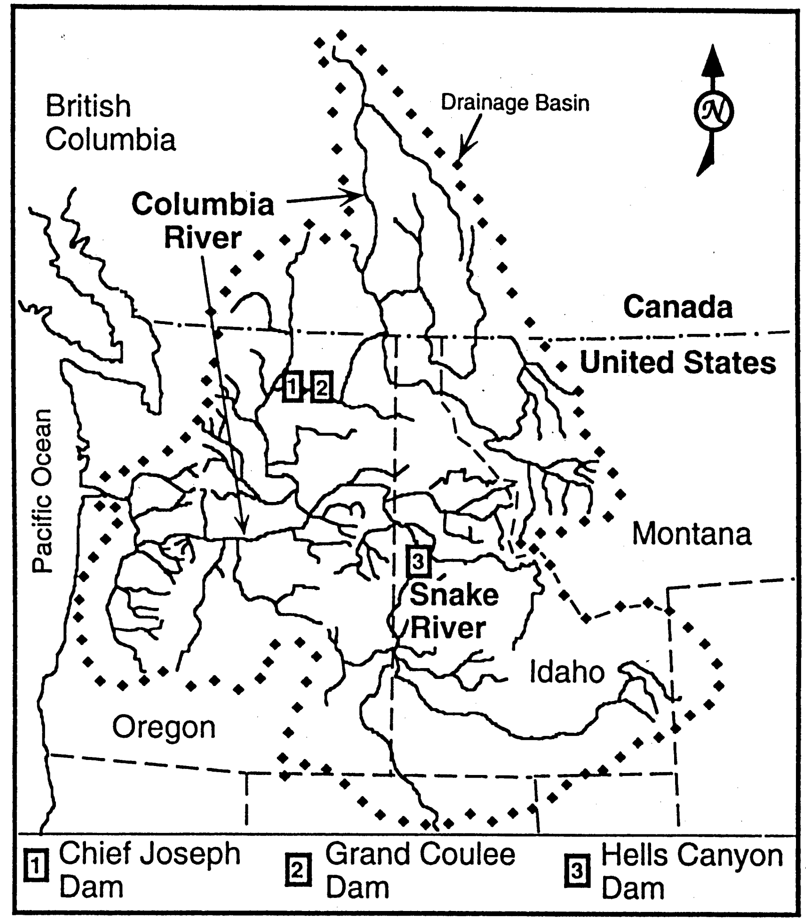

FIGURE 5.1
Drainage basin of the Columbia River (Lee 1993).

Pacific salmon (*Oncorhynchus* spp.), the Columbia's biological web reaches far into the North Pacific Ocean, where the fish mature for 2 to 4 years before returning to their native streams to reproduce. Before European settlement, this ecosystem supported a population of perhaps 50,000 Native Americans (Schalk 1986), whose world centered on the yearly migrations that brought 10–16 million salmon back to the river (Northwest Power Planning Council 1987). Harvested by spear, net, and boat, these fish provided both food and trade goods for the people of the river basin. The Native American tribes lived in a long-run ecological equilibrium, which fluctuated between bad times and good, but endured over many human generations. This original Columbia civilization lasted until about 1850.

Industrial Development

The second human civilization to invade the Columbia basin turned the river into a factory. The basin's nineteen major dams, together with more than five dozen smaller hydroprojects, constitute the world's largest hydroelectric power system. Today dams on the Columbia River and its tributaries generate on average about 12,000 MW from falling water (Northwest Power Planning Council 1991), which is more than enough power to run New York City.

Built largely by the U.S. government between 1930 and the early 1970s—a time of low labor costs and low-cost financing—the dams fostered the industrialization of the Pacific Northwest with cheap electricity marketed by the Bonneville Power Administration (BPA), a federal agency that is now part of the U.S. Department of Energy. The river basin has also become a plantation of more than 3 million acres, watered by some of the largest irrigation works on the planet, including the Columbia Basin Project anchored at Grand Coulee, the largest dam in the United States. Industrial and agricultural development have built the population centers of the Northwest: Portland and the Willamette Valley of Oregon, Boise and Spokane in the upper watershed, as well as Seattle and Puget Sound. BPA remains the economic keystone of the regional economy, and the agency's power sales contracts, together with the water rights that control where water flows on croplands, shape the landscapes of the Pacific Northwest about as decisively as does the weather.

The Native Americans who lived in wilderness have given way to a population of 9 million, more than 100 times the aboriginal level. That increase in population, by two orders of magnitude, reflects a fundamental change in the relationships between people and the environment. The domesticated river provides power and irrigation while also eliminating its once legendary floods; serving as an inland waterway navigable by tug and barge for 500 miles from Astoria, Oregon, near the river's mouth, to Lewiston in central Idaho; affording world-class windsurfing in the Columbia Gorge; and, last but not least, supporting sport and commercial harvest of salmon and other fish and wildlife. Development's dominant theme has been economically efficient management through engineered control.

The industrial Columbia is a multiple-purpose marvel, the product of a national government that saw its central role as the control of nature for economic ends. President Franklin Roosevelt called that role the New Deal, and it was carried forward by Senator Henry M. Jackson and other regional leaders for two generations, transforming the landscape and the people who lived on it. The Columbia became a river, as the historian Donald Worster (1985) put it, that died and was reborn as money,[2] its many functions ranked by their economic value: power first, then urban and industrial uses, agriculture, flood control, navigation, recreation, and finally fish and wildlife. The inferior position of fish and wildlife is evident in the decline of the annual fish runs of 10–16 million in the preindustrial era to 2.5 million by the late 1970s.

As these numbers imply, however, the Columbia has not died entirely. Thus there is hope that, just as the wilderness gave way to the power plant, so a new Columbia may rise, a river whose watchword will be *sustainable* multiple use.

Changing the Rules

Sustainable multiple use is not just a hope. Three intertwined crises have redrawn the rules by which humans attempt to govern the Columbia. Beginning in 1969, Indian tribes of the Pacific Northwest have reasserted their legal rights to harvest fish, under treaties concluded with the U.S. government in the mid-nineteenth century. Today more than $100 million is invested annually in fish and wildlife mitigation. The second change is a large shift in the price of electric energy—crystallized in a crisis over the development of nuclear power—that has raised the importance of husbanding the river's low-cost electricity by innovative and successful efforts to improve energy efficiency. Third, environmental awareness among the voters of the Pacific Northwest—a by-product of the rapid urbanization[3] brought by the harnessing of the Columbia's riches—has supported innovations in institutional relations unimaginable under the industrial order. The changes in fisheries, energy, and political consciousness came together in the Northwest Power Act of 1980, a statute—sponsored by Henry Jackson, a leader of the industrial river basin—that has spurred a search, still in progress, for a new, perhaps sustainable Columbia, a place that would be neither wilderness nor power plant, but an ecosystem requiring active management.

The wilderness the Native Americans knew is gone. Their world was an integral fabric whose natural time scale was the human generation. That cloth has been cut; management by preservation, permitting nature to set the terms on which its constituent species will equilibrate, is no longer possible. Some have questioned whether management by preservation is possible today, even in unpeopled parks and biological preserves (Chase 1987). Yet following the profit motive to its logical end point by increasing energy production as long as its revenues outbid the competing claims of irrigation and other uses is unacceptable. A sustainable Columbia River implies a culturally, economically, and ecologically viable relationship between people and the environment they inhabit. Sustainability would be likely to yield less than the maximum achievable short-run profit, and it would be likely to involve humans in the landscape more than is contemplated in the popular notion of pristine wilderness (Tietenberg 1992).

These statements of what sustainability is not do not specify what sustainability is, nor how to get there. That is why the Columbia basin is searching for a sustainable balance between the electricity that is its most economically important resource and the salmon that are the most emotionally compelling symbol of its natural integrity. The search involves both policy and politics, a combination called *social learning* in the following discussion, in which an idealistic approach to science is combined with a pragmatic approach to politics. It is, inevitably, an uneasy combination.

A Search for Sustainable Management

In 1980 the U.S. Congress passed the Northwest Power Act. This legislation recognized the three crises of fish, power, and environmentalism and created a public arena in which those questions would be worked on. The act was designed to solve a set of social problems by technological means. As demand for power grew during the 1970s, more power plants seemed necessary to utilities. They proposed federal legislation to enable them to finance more plants in 1977. However, citizen activists, whose voices were growing steadily in power and influence, argued that energy conservation could meet the demand for power at lower environmental and economic cost. The search for compromise took more than 2 years. Toward the end of that search, the Indian tribes and fishermen who had fought over the salmon made common cause, demanding that the damage to the Columbia's fish runs be repaired. Rather than choosing among these partially conflicting claims, Congress sought to accommodate them all. The result was a complex law, whose implementation has taken turns unanticipated by those who fashioned its compromises.

To the utilities the major challenge was to build new generating plants to augment the limited supply of hydropower. Pressed by the Bonneville Power Administration during the 1970s, utilities launched five nuclear power plants sponsored by the Washington Public Power Supply System (WPPSS), a public utility consortium based in Washington state but drawing upon the creditworthiness of more than 100 utilities throughout the Northwest. The Northwest Power Act was intended to buttress these arrangements, but it came too late. Plagued by cost overruns, high interest rates, and swiftly falling demand for power in the 1980s, WPPSS completed one plant, mothballed two, and canceled the other two.

Even as Congress hurried to preserve the low-cost power of the Northwest, the costs of new power plants began to come due,[4] and rates increased rapidly. The rise was all the more dramatic because of the low historical base from which it started. From 1979 to 1984 the Bonneville wholesale rate increased more than 700%, and the retail price of power followed, more than doubling on average. At the same time, high interest rates, together with a worldwide economic slowdown triggered by the oil crisis of 1979, depressed the Northwest economy, hitting its energy-intensive industries with gale force. In the rural hinterlands, layoffs and skyrocketing utility bills stirred rebellion.

By 1982, as the Northwest Power Act was in the early stages of implementation, the expected power shortage that had motivated its enactment had evaporated. Demand was far below expectations because the economy was in recession. With rates rising rapidly, conservation gained plausibility. Instead of a deficit, there was a surplus of power through the 1980s. Instead of a financing mechanism to build new power plants, the Northwest Power Act became the blueprint for a laboratory of energy and environmental conservation. By the end of the decade energy conservation had produced the equivalent of a small coal-fired power plant at roughly half the cost. More important, the success of conservation meant that official plans to meet growing electricity demand now took energy efficiency as the preferred alternative.

The claims of Indian tribes posed another threat to the region's industrial order. In 1855 treaties between the U.S. government and the Northwest's Native Americans created reservations within which the native peoples agreed to live while retaining rights to fish, hunt, and gather roots and plants over a territory well beyond the reservation boundaries "in common with" the settlers. That language would reverberate more than a century later. At the time it seemed not to concede much—it afforded the Indians their traditional livelihood, and there was plenty to share "in common."

Beginning in 1969, after the settlers and their descendants had transformed the landscape and obliterated many of the fish runs, the Northwest tribes filed, and won, lawsuits to claim their treaty rights. The immediate result was to reallocate shares of the salmon harvest, since "in common with" meant that Native Americans were entitled to harvest half the fish. Such a drastic and sudden curtailment of a fishing industry already in decline struck hard at commercial and sport fisheries that had ignored the Indians since the treaties were signed. After a decade of hard feelings, as the lawsuits made their way to the Supreme Court—where the treaty claims were affirmed—both non-Indian and tribal leaders realized that there was only one option all could abide: to rebuild the salmon populations so that there would once again be enough for all to take "in common" without battling one another for the right to kill off the stocks forever. Although this reality was articulated by Tim Wapato, the politically astute negotiator who led the Native Americans of the Columbia basin, no one knew how to rebuild the salmon runs; it was clearly going to be expensive, however.

The Planning Council

The government could legislate and tax, but it could not make kilowatts or fish. A law could not solve the problems of salmon or power, but it could arrange for their solution over time. The Northwest Power Act used a familiar strategy of governance, defining a new process, so that an array of choices could be made without further appeals to Congress or the courts. So far the strategy has been successful: After an initial

flurry of litigation over the meaning of the act for power sales contracts and other legal matters, judicial activity has ceased, and despite concerns over endangered salmon, there is little prospect of new legislation.

The centerpiece of the new process is the Northwest Power Planning Council and the two plans it has promulgated—each several times—with wide public involvement. Chartered by the four Pacific Northwest states of Idaho, Montana, Oregon, and Washington, the council is composed of two members from each state, appointed by the governor under procedures established by state law. Under some circumstances the council has the unusual authority to restrict or redirect the actions of federal agencies. The council is in effect an interstate compact, a form of government organization that shares both state and federal authority.

Power Planning

The council's primary task is to formulate a plan to guide electric power development, including energy conservation. Three versions of the plan have been issued, the most recent in 1991. The plan's central premise is regional cost effectiveness, planning that minimizes costs across the Pacific Northwest's many utilities, a rule that the fragmented industry would not naturally follow. As noted earlier, the plans have induced investment in energy conservation, making this approach credible and feasible among the region's utilities, regulators, and energy consumers. About 300 MW of new demand has been met by existing supplies, because that quantity of existing demand has been eliminated by an investment of $600 million in energy-efficient technology; the cost ratio is about half of that required to build a coal-fired power plant in this size range.

The acceptance of the power plans has had a more subtle cultural influence, raising the legitimacy of a rational response to the uncertainties brought by large-scale change in the cost of energy. Rising costs affected different utilities in different ways, because power from the Columbia's dams was a large fraction of operating expenses in some cases but not in others. Some utilities were growing rapidly, and thus needed additional supplies of power, whereas others were not. Institutional fragmentation would have been the natural outcome of this situation, and all utility managements have moved toward greater vigilance of their own self-interest in dealings with BPA and other utilities. The presence of the council and its regional planning process has made regional information a public resource, however. Information in the form of demand forecasts and publicly debated plans to offer energy efficiency programs or to build generating resources has made it possible for utilities and citizens to estimate their own self-interest in ways that were not feasible before. In an industry in which the economic fate of nominally independent entities is actually coupled together by investments in transmission networks, dams, and other large facilities, making decisions in public and on a rational basis is helping to redefine the social function of utilities and the energy they provide.

The Columbia River Basin Fish and Wildlife Program

In an attempt to address the disruptive potential of Indian treaty rights litigation, Congress included in the Northwest Power Act directives meant to provide fish and wildlife "equitable treatment" in comparison to hydropower. In response, the Northwest Power Planning Council adopted an ambitious Columbia River Basin Fish and Wildlife Program in 1982, subsequently amended in 1984, 1987, and 1992, calling for a broad spectrum of mitigating activities.

Implementation of the council's program is funded from revenues that the Bonneville Power Administration charges its electric power ratepayers. The council has determined that losses of salmon and steelhead due to hydropower amount to between 5 and 11 million adult fish per year (Northwest Power Planning Council 1987). The result is an effort to rehabilitate fish and wildlife on an economic scale unheard of in natural resource management, with an economic cost of over $130 million per year. Since its reformulation in 1987 into a program that is explicitly "systemwide" in conception, the Columbia basin program has organized mitigation activities into the three principal points at which human activities intersect the salmon life cycle—at the point of harvest in the oceans and rivers, with hatcheries and habitat conservation at the time of birth, and during migration through the dams, when the fish are juveniles bound for the sea or are returning as adults.

Harvest of Pacific salmon is now being regulated by the states and tribes of the Pacific Northwest and by Canadian and U.S. governments, both to conserve and rebuild fish stocks and to assure fair apportionment of the catch. The regulations, determined annually, implement the terms of a treaty between the United States and Canada signed in 1985, as well as the treaties governing relations between Indian tribes and the U.S. government.

Enhanced production of fish is in progress, by artificial means, such as hatcheries, and via protection and improvement of natural spawning grounds. Several new hatcheries will be built in the basin to supplement the more than 100 artificial production facilities now operated by state and federal governments. The existing hatcheries are mostly in the lower river, below the traditional fishing grounds of the Columbia basin Indian tribes; the new facilities will be upstream, where traditional tribal harvest sites are located. The present intention is to use the hatcheries to raise fish only until they can survive in the wild. Juveniles would then be put into streams where they would imprint the smell of their adopted waters at the time of migration. This way the fish should return as adults to these streams, rather than to the hatchery. If enough adults do so, a natural spawning run will be reestablished, independent of the hatchery.

Natural spawning habitat is being improved primarily by reopening fish passages that were blocked by earlier human usage. For example, in the Wenatchee River of eastern Washington, Dryden and Tumwater Falls dams, originally built without fish ladders, have been equipped with passage so that migrating adults can now reach the habitat blocked by the dams.

The council has also identified 40,000 stream miles of "protected areas" where small hydroelectric projects should not be built. The council advises the state and federal agencies responsible for hydroproject licensing, particularly the Federal Energy Regulatory Commission, which is directed by statute to take the council's program "into account at each relevant stage of the decision-making processes to the fullest extent practicable" [U.S. Congress 1980, sec. 4(h)(11)(A)]. As a result, even though the council has no explicit regulatory authority over landowners, its legal influence over the federal commission effectively protects salmon habitat against hydropower development, a leading threat.

The most costly and controversial elements of the Columbia basin program are intended to enhance the upstream and downstream migration of anadromous fish in the main stem of the Columbia and its principal tributary, the Snake. In some years more than 80% of migrants from the upper Snake and Columbia are individually marked before being transported in barges to the river's estuary. In an effort to protect the fish that are not transported, Congress has also appropriated more than $30 million annually to install screens and carve bypass channels in dams to deflect young fish away from power turbines. Most ambitious of all, perhaps, the river's flow has been altered to benefit fish migration, at an annual cost of more than $40 million in lost power revenues. The revenues are diminished because water is released in the spring and summer, when it benefits fish, rather than being held back until autumn or winter, when higher prices can be obtained for the power.

The key measure, known as the water budget, re-creates the spring snow melt or freshet, providing a substantial volume of water to flush migrating juveniles to the sea. The water budget is a more generous compromise for the Columbia than for the Snake, because the upper Columbia discharges more water and has substantially more storage in its upstream dams. In practice, even the water dedicated to the water budget in the Snake River drainage has often been unavailable. In 1987 the council staff analyzed the relative abundance of salmon stocks in the Columbia basin and discovered five that were so depressed that their biological viability was clearly in jeopardy (Nehlsen, Williams, and Lichatowich 1991). Four of the five were in the upper Snake River drainage. By 1990 all five stocks were the subjects of petitions for listing as endangered species under the federal Endangered Species Act (Volkman 1992). In response, the council convened a year-long "salmon summit" that tried to negotiate a consensus approach to benefit stocks under extreme pressure. The result, adopted by the council in 1992 as an amendment to its fish and and wildlife program, forms the starting point of a recovery plan now being formulated by the National Marine Fisheries Service under the provisions of the Endangered Species Act.

Biological Uncertainty

The policy problems of the water budget illustrate the problem of searching for a sustainable way to manage the river. The biological benefits of the water budget are hard to see, in part because of its small size in comparison to natural fluctuations. Figure 5.2 shows a compilation of data from the Snake River on the relation between the volume of river flow and average travel time for migrating juvenile fish. This handful of measurements—the black dots in figure 5.2—constitutes the principal justification for losing $40 million per year in power revenues.

Each data point represents a measurement of how fast a typical juvenile salmon moves down the river, depending on how much water the river is carrying. Like riders on an escalator, the fish should go faster when the river flows faster—that is, when the flow level is higher. Therefore the data points should trend down to the right; the higher the flow, the shorter the travel time. The downward-pointing straight solid line

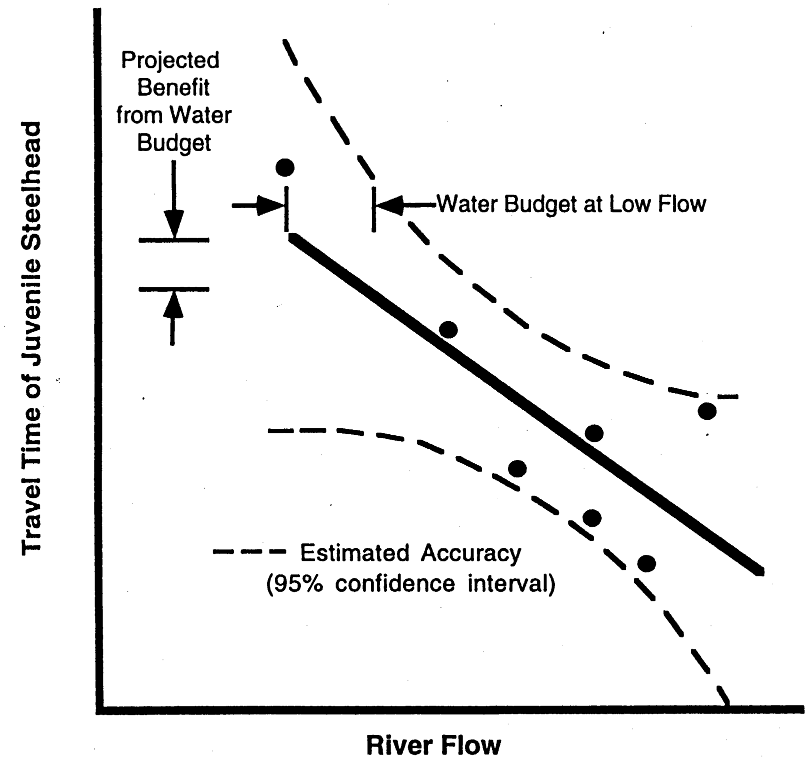

FIGURE 5.2
Effect of the Snake River water budget on juvenile salmon migration. Both vertical and horizontal scales are logarithmic. For consistency, the flow at Ice Harbor Dam is used as the standard measure of flow. The water budget in the Snake River (horizontal arrows) is superimposed on the measured relationship between river flow and migratory fish travel time. The projected reduction in travel time (vertical arrows) as a result of the water budget lies well within the measurement error (curved lines). Therefore the effectiveness of the water budget in speeding juvenile fish downstream is difficult to prove. (Northwest Power Planning Council, after Sims and Ossiander.)

represents the spring runoff in quantitative terms—the biological benefit, measured in reduced travel time, plotted against economic cost, measured in river flow. The water budget, shown as an increase in flow in the figure, should therefore produce a biological benefit.

The concept is straightforward, but there are complications. First, there are few measurements. Each point represents a sizable investment of research time and technical effort—marking, releasing, and recapturing thousands of migrating juvenile fish at dams hundreds of miles apart, to see how long it takes them to migrate downstream. At most a single data point is measured in a year, not only because of cost, but because different levels of river flow are needed to see how fish and flow relate to each other. Each year one sees no more than one Columbia—a wet one this year, perhaps, a drier one next, and so on.

Second, although the relationship shows the expected trend—the higher the flow, the lower the travel time—the observations do not lie along a single line; there are fluctuations and "noise" in the data. The relationship between travel time and river flow is affected by other factors, many of them unmeasured. For example, the condition of the fish when they start migrating can make a large difference, but trying to pinpoint the health and readiness of thousands of fish the size of a human finger is too expensive and time-consuming to be practical.

Third, the uncertainty is large relative to the size of the water budget. The effect of the water budget is largest when the flow is lowest, at the left side of the graph, because the effect of a fixed volume of water is largest when the underlying flow is lowest. Yet even under these conditions, the *change* brought about by the water budget lies well within the dotted lines, indicating the range of uncertainty in the available data.[5] The biological effectiveness of the water budget, even if it were fully implemented, would be difficult to observe, even in low-water years, when one would expect it to be most helpful.

For these reasons the idea of dramatically increasing the volume of flow of the Snake River during the salmon migration season was resisted fiercely by utilities and farmers whose irrigation waters would be drained at the start of the growing season. Instead, the new salmon strategy devised by the council experiments with an operating method called "drawdown": The reservoirs behind several dams are lowered, forcing the river to flow in a narrower channel; a smaller augmentation of the volume of flow is then able to produce a higher flow velocity. The drawdown method is now being studied to see how well it works.

Budgeting for Conservation and Fish

Oddly, it is easier to pay for sustainable management of the Columbia because of the failure of nuclear power in the Pacific Northwest. The wholesale cost of electric power soared more than 700% in the early

1980s (Bonneville Power Administration 1988), largely to pay for nuclear plants never completed. Thus the revenue stream is much larger than anticipated, and the percentage needed to pay for conservation and fisheries has been relatively small. The cost of the fish and wildlife program consumes about 1.5% of the Bonneville Power Administration's annual budget of roughly $3 billion.

The search for sustainability in the Columbia basin proceeds, accordingly, under conditions where budgetary limitations are only a secondary consideration. This condition is clearly unrepresentative of attempts to carry out sustainable development generally, so the Columbia River case should be regarded as no more than a proof of principle—a demonstration that the serious pursuit of sustainability can be launched.

A problem in the Columbia that is more representative is the large number of hands on the steering wheel. The Columbia River Basin Fish and Wildlife Program is implemented or significantly influenced by eleven state and federal agencies, thirteen Indian tribes, eight utilities that operate major hydroelectric projects in the Columbia drainage, and numerous organized interests ranging from agricultural groups anxious to protect water rights to flyfishers impatient for the return of wild fish stocks. If the river is to revive in any sustainable sense, it will have to be managed with a stability, durability, and awareness of biology rare in human affairs.

Mindful of the complex institutional repercussions of the changes it was making, the council adopted the concept of adaptive management in its fish and wildlife program in 1984, and expanded the idea into a process called *system* planning in 1987. System planning was intended to institute an experimental approach to implementation. The recasting of the search for sustainability brought about by the petitions under the Endangered Species Act has made clear the fragility of an experimental approach and the central role of political conflict in social learning.

Social Learning

The Columbia basin experience illuminates the *social learning* that is needed to search for sustainable development. Today humans do not know how to achieve an environmentally sustainable economy. If we are to learn how, we shall need two complementary sorts of education. First, we need to understand far better the relationship between humans and nature, that is, *adaptive management*—treating economic uses of nature as experiments, so that we may learn efficiently from experience.

Second, we need to grasp far more wisely the relationships among people. One name for such a learning process is politics; another is conflict. We need institutions that can sustain civilization now and in the future. Building them requires conflict, because the fundamental interests of industrial society are under challenge. But conflict must be limited because unbounded strife will destroy the material foundations of those interests, leaving all in poverty. Bounded conflict is politics.

This combination of adaptive management and political change is *social learning.* Social learning explores the human niche in the natural world as rapidly as knowledge can be gained, on terms that are governable, though not always orderly. It expands our awareness of effects across scales of space, time, and function. For example, we pump crude oil from deep within the earth and ship it across oceans; we burn in a minute gasoline that took millennia to form; with petroleum and its end products we foul water, soil, and air, overloading their biological capacity. Human action affects the natural world in ways we do not sense, expect, or control. Learning how to do all three lies at the center of a sustainable economy.

Adaptive Management

There are two critical elements in the transition to sustainability: biological uncertainty and institutional complexity. In seeking a path from the unsustainable vitality of industrialism to a sustainable order, learning from experience is the only practical approach. Without signposts the path to sustainability is easily lost. Consider some of the difficulties on the way (Hilborn 1987):

- *Data are sparse.* It is difficult to observe the state of the ecological system and the human economy interacting with it. Measurements of the natural world, such as the size of migrating populations, are inexact at best, and natural systems often yield only one data point per year (e.g., river flow).
- *Theory is limited.* Reliable observations are few, and theories of natural environments do not permit deductive logic to extrapolate very far from experience. Also, the perturbations caused by humans are frequently both large and unprecedented in natural history, so that it is unclear what theory is applicable.

- *Surprise becomes unexceptional.* With limited theory comes poor knowledge of the limitations of theory. Predictions are often wrong, expectations unfulfilled, and warnings hollow.

A general strategy has been devised to deal with natural resources under these conditions. The approach is called *adaptive management,* a term coined by C. S. Holling and co-workers at the International Institute for Applied Systems Analysis (Holling 1978; Walters 1986). Their work is built on a simple, elegant idea: If human understanding of nature is imperfect, then human interactions with nature should be experimental. That is, policies should be designed and implemented as experiments probing the behavior of the natural system. Experiments often surprise and scientists learn from surprises. So if resource management is thought of from the outset as an experiment, surprises are opportunities to learn rather than failures to predict. Adaptive management holds the hope that, by learning from experience, one can reach and maintain a managed equilibrium efficiently, with a resilience able to persevere in the face of surprise (Clark and Munn 1986).

Adaptive management originates in a comprehensive ecosystem perspective, in which the interactions among the components of the natural environment are highly structured, and the behavior of the system as a whole is consequently rich in surprise. Proceeding from a base of careful observations, experimental interventions into this interacting system provide insights into its dynamic character—insights, such as the longstanding belief that diversity reinforces stability, that are helpful even when they are not universally valid, useful even when one cannot rely implicitly on their quantitative implications. The adaptive perspective begins from a scientific viewpoint, and its continuation into the realm of action is informed more by the observational interest of a naturalist or astronomer than by the manipulative tendency of the engineer or entrepreneur.

Adaptive management is ecologically rooted in two more specific ways. First, the adaptive perspective is linked to biological time scales, because the effects of experimentation on a population often become visible only when measured over generations. For salmon this implies times of 5 years or more—a long interval in a governmental world, where senior policy officials serve terms shorter than the salmon life span. Second, the adaptive approach focuses on populations, not individuals. Failures are often fatal for individuals but rarely for populations.

There is, accordingly, a greater willingness to experiment when the unit of concern is the population.

Even if whole populations are being managed, however, the decisions are made by individuals. Put into governmental terms, a policy maker who regards each choice as an opportunity to succeed or fail may be reluctant to venture into the chancy—if realistic—terrain of adaptive management. Though the theory emphasizes the value of learning from failure, it requires individuals with a high tolerance for risk to carry it out. As in economics, where the theory emphasizes the benefits of competition, the risks facing individuals can be imposing.

Although virtually all policy designs take into account feedback from action, the idea of using a deliberately experimental design, paying attention to the choice of controls and the statistical power needed to test hypotheses, is one rarely articulated and usually honored in the breach. It is for this reason that the explicit adoption of an adaptive policy in the Columbia River Basin is noteworthy.

Negotiating Consensus

Adaptive management responds to biological uncertainty, but it is not clear how the adaptive approach can work in the presence of institutional complexity. That many interests have stakes in the transition to sustainability is hardly surprising, but finding and maintaining a balance among disparate and often noncomparable considerations, such as irrigation and tourism, is evidently a political task, one that may not be consistent with the rational pursuit of knowledge through adaptive management.

Because control over large ecosystems is fragmented, the search for a sustainable economy requires extensive social interaction: sharing analytical information, such as simulation models and data bases; identifying trade-offs and coalitions for joint action; and learning from surprising outcomes. These interactions are ways to negotiate shared agendas that individual organizations cannot achieve by themselves.

The central role of negotiation emerges from the surprising blend of technocracy and consensus building that has gained visibility and favor among natural resource managers over the past decade (Amy 1987). In cases previously characterized by lengthy litigation and embittered conflict, informal negotiations have produced plans of action acceptable to traditional adversaries: tribes and state governments, environmentalists and developers, and resource managers and harvesters. Although wary of advocacy in the guise of science, the parties have found it possible to use technical analyses and have invented measures to assure the political and scientific credibility of analysts and their findings. The negotiated agreements have included joint oversight mechanisms, because unforeseen circumstances are to be expected during implementation. As a social process, the negotiations have sought to achieve and maintain the measure of consensus necessary for experiential learning to occur. Thus consensus-building negotiations have created the open political environment that is necessary for adaptive management.[6]

Consensus building is central to sustainable development as well, because the natural systems being managed cross the spatial and functional boundaries of existing human institutions. Without a comprehensive perspective, the fragmentation of jurisdictions promotes abuse of the environment, because individual institutions seek to achieve purposes that often turn out to be incompatible with sustainable use of the whole; this is the tragedy of the commons (Hardin 1968). Yet implementation requires a decentralized, fragmented perspective, because decisions are carried out by parties whose responsibilities are narrow compared to the breadth of the analytical tools used by planners (Baskerville 1988).

The complexity of both human and natural systems is high enough to outrun anyone's ability to command from a central vantage. Building consensus by negotiation can link central perception to decentralized action. Consensus may also improve long-range plans to rehabilitate ecosystems.

Remedial actions require consensus when they encounter problems of economic sustainability. Damages from past actions are a sunk cost: The value of the resource has been taken by the exploiter and is no longer available to pay for remediation. The damaged ecosystem also contains hidden opportunities, since the ability of natural systems to recuperate is often uncertain. In that circumstance strict cost–benefit estimates are likely to undervalue the worth of rehabilitating the ecosystem, especially if it is difficult or impossible to fund rehabilitation from the profits of exploitation (Regier and Baskerville 1986). When these conditions occur, a negotiated consensus reflecting a mandate for rehabilitation is needed to justify expenditures. Moreover, past damages may have altered the political environment by driving out a group of resource users (such as the Native Americans of the Columbia basin). In that event, rebuilding a sustainable suite of uses may require that points of view silenced by earlier misuse be actively sought out. Consensus building has been strategically important in the Columbia River Basin, where a central agent finances decentralized actions, no one of which meets a narrow cost/benefit test, even though their cumulative impact may be economically sound.

A consensus that fosters learning both facilitates and benefits from an open political setting. By lowering the barriers to participation and, in effect, organizing their own political environment, planners can negotiate and sustain a pluralist, competitive political setting in which disparate considerations can continue to be weighed as learning goes forward.

Planning and Politics

This consensus-building approach can be seen in the work of the Northwest Power Planning Council (Evans and Hemmingway 1984). Because important matters are at stake in development projects, a wide spectrum of interests is motivated to participate in the planning. Barriers to participation should be low at the outset and can be kept low by the planners. Established relationships are usually weak at the beginning of a development project, and because there is often substantial uncertainty about how the links among different interests will be changed, it does not require much previous experience to become an effective player. Where external support is important to the implementation of the plan, however, planning must turn to the outside world.

Backed by a legal mandate to keep the public informed and involved, the council lowered barriers to participation and judged its success by its credibility with the public. The council's first chairman, Dan Evans, a popular and well-known figure who had served three terms as governor of Washington state, led the way with an open political style. Evans made a special effort to approach the Native American tribes, whose legal battles on fishing rights began to be fought while he was governor. More generally, the council approached organizational and opinion leaders both in and out of government and consciously developed a constituency for implementation of its energy plan and fish and wildlife program. Support for the council came almost entirely from organized groups because of the complexity of the council's plans. Despite the wide popularity of efforts to protect and enhance the fish runs, the work of the council has not been visible to the public at large. Instead, the council cultivated a reputation for well-informed, even-handed judgment among organized interests. This low visibility was a

liability when the Endangered Species Act petitions were filed and critics of the council's approach sought drastic change (Blumm and Simrin 1991). Yet the strength of the institutional network fostered by the Northwest Power Act became apparent during the salmon summit negotiations: The broad scope of the conflict over how to respond to the decline of the salmon runs required adjustments from a wide spectrum of powerful economic interests. Although the council did not develop a consensus to which all agreed, it did formulate a salmon strategy that no one disagreed with so strongly as to seek to upset it; moreover, the strategy has the backing of the four Northwest state governors, a considerable degree of support given the potential for economic disruption.

This kind of planning constitutes an institutional style: gathering information from sources throughout the basin and subjecting the data to public review as a prelude to a public process of priority setting. Building an institutional structure for sustainable development in the Columbia River basin has been based on several conditions:

- Commitments in law, reinforced by political support, to preserve and enhance environmentally valued resources.
- Explicit recognition of ecological, economic, and social uncertainties.
- Acceptance of conflict as an indispensable element of social learning.
- A commitment to act on the basis of knowledge.
- Adequate funding.
- An institutional process open to experiential learning, including conflict.
- A systems orientation.

Changing Myths

The emergence of social learning as an approach to the Columbia can be understood as a change in governing myths, a shift in the way people imagine their place in the natural landscape they inhabit. Table 5.1 rearranges the chronicle to bring out this change in myths—a change only partially perceived by the actors themselves.

From the construction of the first dam on the main stem of the Columbia in 1930 until the enactment of the Northwest Power Act in 1980, the Columbia Basin was an industrializing economy, in which natural resources were treated as economic assets. The transition be-

Table 5.1
Elements of the Shift from an Industrial Order to a Search for Sustainability in the Columbia River Basin

Element	Industrial (1930–90)	Searching (Since 1980)
Myths	Economic return is social objective	Sustainability is social objective
	Control of nature through engineering and mastery of fluctuations	Adaptation to nature through management and learning; acknowledgment of uncertainty and natural time scales
	Energy of primary economic importance	Low-cost energy, obtained through energy conservation, economically important Environmental quality, including healthy salmon populations, socially important and worth a significant (but not unlimited) measure of economic sacrifice
	Electric power producers and irrigators dominant	Fish and wildlife interests play a legitimate role in constraining exploitative use
	Management should be centralized	Decisions should be negotiated in open processes
	Politics should be subordinated to rational, technocratic management	Political conflict is inherent in renegotiation of social priorities. Political conflict is crucial for the recognition of errors. Negotiated consensus is nonetheless necessary if scientific study is to be possible over times of biological significance.
Key institutions	Bonneville Power Administration, operators of major dams	Northwest Power Planning as a forum for negotiation among existing institutions and interests
	Power sales contracts Water rights	Native American treaty rights Endangered Species Act
Key events	Building of dams and irrigation system	Indian treaty rights litigation
	Commercial salmon harvest	Nuclear crisis
Key people	Franklin Roosevelt, Henry Jackson	Tim Wapato, Dan Evans

yond industrialism toward a search for sustainability is marked symbolically here by the passage of the Northwest Power Act. Yet, like all social transitions, the process has been punctuated by conflict and crisis, and its outlines are still taking shape. Indeed, if an ecologically and economically sustainable order is achieved, it will not be visible for some time, simply because sustainability implies stability in long-term averages, which cannot be established rapidly by definition.

Social learning entails wrenching changes in beliefs. These are not obviously matters of ideology in the usual sense, for acknowledgment of uncertainty and natural fluctuation is neither liberal nor conservative. Rather, the beliefs that have yielded to changing circumstances have to do with whether humans can control nature, or whether they can prosper by making intelligent use of limitations on control. The idea is implicitly economic and cognitive: The cost of control may be unaffordably high; human efforts should seek a satisfactory level of influence upon the forces of nature and human activities should avoid irreversible damage to natural systems.[7]

Human institutions are the channels of change. Organizational routines and ways of allocating the attention of decision makers shape their perception of and response to surprising changes. To say that institutions are important is not to say that institutional processes produce orderly change, however. Because social learning is a conflict-ridden process, choices are characteristically made in an anarchic fashion, in which institutionalized patterns of behavior generate outcomes that can seem irrational to those participating in the processes (Kingdon 1984). Certainly the utility leaders who sought to preserve nuclear energy as a viable means of supporting the growth of an industrial society did not imagine that their labors would lay the economic foundations for an ambitious attempt to rebuild salmon. Yet the much higher electricity rates that followed the nuclear crisis made salmon rehabilitation affordable.

For the same reasons, the events and people whose actions would cast long shadows are difficult to identify in real time. Thus the philosopher Hegel spoke of the owl of Minerva: History's shape is discernible only at dusk, when the battle is over. This does *not* mean that one must be resigned to an existential fatalism, however. Because institutions and the beliefs they embody are influential, it is paradoxically more important to assure that the basis of those beliefs is well founded. Only then can actions taken in the press of incompletely controlled change be guided by reliable knowledge. That is why adaptive management, the testing of experience against the organized skepticism of science, is an essential element of social learning. The political challenge is to support adaptive management through the turbulence of change. Dan Evans's most significant contribution as founding chairman of the Northwest Power Planning Council may therefore be his dictum that, in a situation of high uncertainty, "the best politics is no politics." Similarly, Tim Wapato's quiet investment in biological training for the Native American field staff who began to take their places alongside the non-Indian resource managers responsible for the salmon may turn out to be his most durable legacy.

Three Caveats

The challenge of a sustainable Columbia River is no different from the challenge of sustainable development generally. Can humans endure on this planet? Nobody knows. It is clear that continuing the exponential increase in resource use of the past 150 years will have serious effects on the global climate. Yet stalling the rush toward the inhospitable greenhouse raises profound questions of economic justice and strains the ability of the international system to maintain order. Although it is necessary to proceed adaptively in the search for sustainability, learning from experience may be neither sufficient nor feasible in the transition ahead. Three caveats are in order.

1. There is the problem of conceptual tractability. The natural systems to be managed sustainably are inherently complex, and their complexity exceeds both traditional human comprehension and the institutions that have managed portions of them in the past. Complexity is a barrier to sustainable development.
2. Moral viability is another problem. Perhaps only rich, stable nations can afford sustainability and make the transition with some semblance of political consent. The concept of sustainability comes with no guarantee that it is attainable or that, if feasible by some quantitative measure, it will be politically and morally palatable.
3. Social learning emphasizes the interest of the population, not that of the individual. Belief systems that value individuals may find little comfort when learning comes at a high cost in suffering. The long delays inherent in many aspects of global sustainability also limit the utility of adaptive methods, since the signals of success or failure may come back too slowly to inform action. These are the same conditions one encounters in social welfare policy: slow or incomprehensible feedback, combined with urgent, undeniable individual needs. Thus far, social welfare programs have been more anodyne than cure.

The experience of the Columbia River Basin points to two unorthodox paths for study and reflection. First, look to the industrial economies for examples of sustainability. Sustainable development may be like the demographic transition: Nations rich and stable enough to be able to experiment with different modes of living may discover the viable alternatives.

Second, the strategic importance of uncertainty on the path to sustainability must be considered. The adaptive approach offers a conceptually sound way to deal with uncertainties in the natural system and with the complexities of institutional structure. Thinking in terms of whole systems while acting through fragments ("think globally, act locally") requires an explicit organizational and political strategy. Social learning is such a strategy.

Taking sustainability seriously is a question of governance. There are promising leads, but time is short and resources are dwindling. Learning what does not work is a cost of finding ways that will. Minimizing that cost preserves humanity's already limited ability to pursue sustainability with justice and mercy.

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NOTES

1. Lee (1993) provides more extensive discussion of social learning. Detailed discussion of the Columbia Basin experience in energy conservation and salmon rehabilitation, with full references to the literature, is in Lee (1991a, 1991b); see also Northwest Power Planning Council (1987, 1991).
2. Worster was commenting on the Colorado River.
3. On the importance of rising economic welfare in the formation of

environmental consciousness, see Hays and Hays (1987), who describe environmentalism as part of the "history of consumption."

4. In traditional utility practice, the cost of a new power plant is not counted as part of the "rate base," or invested capital, until it goes into service. Ratepayers are consequently shielded from the cost impact of utility managers' investment decisions until power is delivered; by that time it is generally too late to affect the project. In the Northwest the costs of the first three WPPSS nuclear plants were financed by Bonneville, but the cost impacts were delayed by the financing arrangements until 1979. Since then, even though only one of the plants is in service, the costs of all three are being recovered through Bonneville's rates.

5. The dotted lines in the figure reflect a 95% confidence level; that is, there is a 95% probability that the true trend line will fall within the dotted lines. A lower confidence level would allow the dotted lines to fall closer together. The fact that the observed data are already close to the dotted lines, however, indicates that a more relaxed confidence level would not change the conclusion stated in the text. No statistical manipulation will make the noise in the data go away; only a longer series of observations can do that.

6. Negotiated consensus may not be a necessary precondition for adaptive management. The simultaneous emergence of negotiated settlements to natural resource disputes and of adaptive management appears to be a historical accident, though it is clear that both draw upon ideas "in the air," including a bias for consensus as a management style and a commitment to use science in decision making despite conflict.

7. For a general formulation of the procedural rationality reflected in this approach, see Simon (1983).

6

Barriers and Bridges to the Restoration of the Great Lakes Basin Ecosystem

George R. Francis and Henry A. Regier

The Great Lakes are in a class by themselves. Their size and the fact that they are the world's largest set of freshwater resources assure this. The 766,000-km^2 drainage area of the Lakes, which serve as a huge headwater region for the St. Lawrence River system, is home for some 38 million people. It is also the location of the urban and industrial heartland of North America. This heartland sprawls over the southern portion of the basin while, economically, the northern portion serves as a vast resource-based "hinterlands" for the heartland and beyond (table 6.1). The governing framework for the basin is set by the two constitutional federalisms, which through historical compromises some two centuries ago, extend to the middle of four of the lakes and their connecting channels (rivers). This regional ecosystem is equivalent in its geographic scale, human population, economic base, and institutional complexities to a medium-sized industrialized nation-state.

The Great Lakes have inspired many superlatives from those who have written about their natural features and aesthetic vistas (Ela and King 1977), the history of resource use (Waters 1987), and the sagas of commercial shipping over the years (Stephans 1930; Willoughby 1961; Havighurst 1975). Unfortunately, the urban/industrial heartland and some of the resource extraction industries in the basin have taken their